A Flight at Sunset. The Hanriot Monoplane in Mid-air

Monoplanes and Biplanes

Blue

THEIR DESIGN, CONSTRUCTION AND OPERATION

The Application of Aerodynamic Theory with a Complete Description and Comparison of the Notable Types

By

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278 ILLUSTRATIONS

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PREFACE

AVIATION has now advanced to the stage where a practical exposition of the subject is widely demanded. Many so-called "popular" books have been written, and contain much that attracts the attention of the average man, but little if anything that appeals to the more serious student of the subject. On the other hand, many valuable treatises have been written, but of so scientific and mathematical a nature that they are almost unintelligible to all but a few technical men; and in many cases it must be acknowledged that mathematics often lead to conclusions that are wholly at odds with the actual results of practice.

In this book, therefore, the author has made it his purpose to present the subject of "the aeroplane" in a manner that is at once intelligible and of interest to the average man, as well as of value to the more learned student.

Much of the work involved in the writing of this book was done in fulfillment of the requirements for the degree of Master of Arts at Columbia University. This work, largely in the nature of research, was under the direction of Dr. Charles C. Trowbridge, of the Department of Physics, to whom the author is naturally indebted for many valuable suggestions and much friendly aid.

The author's thesis accepted for this degree was published serially in the Scientific American Supplement, Nos. 1816-1822, inclusive, and forms the nucleus of this work. But the progress in the subject is so rapid that more than twice as much new matter has been added.

After an historical introduction in which the inestimable value of the work of Langley, Lilienthal and Chanute is

pointed out, the design of aeroplanes is taken up. The theory of Aerodynamics is given as simply and completely as possible, and the fundamental principles are everywhere fully explained and emphasized. At the end of this section is given a complete example of the design of an aeroplane, which should prove of particular value to those actively engaged in aeroplane construction.

The monoplanes and biplanes in their various forms are then considered. Detailed descriptions of virtually all of the present successful types are given, supplemented by photographs and diagrams reproduced to the same scale, thus at once enabling a graphic comparison. Many of the types are changed from time to time and the data is in many cases unreliable, but the author has spared neither time nor effort to render this section as exact as he was able to. Were the leading machines here described not to remain substantially the same for years to come, they should, nevertheless, prove of permanent value in that they represent distinct types with which concrete results were first obtained.

In the last part of the book, the leading types are compared and discussed, and from the results of actual practice conclusions are drawn, enabling the lines of probable future development to be pointed out. This section will prove of interest to almost every one, as it is the author's experience that the knowledge of this subject possessed by the average person is far greater than most writers suppose.

The numerous tragic and in many cases avoidable accidents constitute, probably, one of the greatest detriments to the progress of aviation. Their causes, and as far as possible with the meagre knowledge available, the means for their prevention, are considered in this section; and the fact that aviation is reasonably safe can unquestionably be concluded therefrom.

The closing chapter of the book deals with the "variable surface aeroplane", a development which the author believes to be the next great step forward in the rapid progress of aviation.

The author wishes also to express his appreciation of the valuable favors, information and assistance which he has received from Prof. Wm. Hallock of Columbia University, Prof. Carl Runge of Goettingen, Mr. Wilbur Wright, Mr. A. M. Herring, and Mr. Ernest L. Jones, editor of "Aeronautics".

The kind offices of Messrs. Stanley Y. Beach and John J. Ide have greatly facilitated the author's work.

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PART I.

THE DESIGN OF AEROPLANES

HISTORICAL INTRODUCTION—AERODYNAMIC THEORY—AEROPLANE CALCULATIONS

INTRODUCTION

CHAPTER I

In his immortal "Rasselas," Dr. Samuel Johnson says, "instead of the tardy conveyance of ships and chariots, man might use the swifter migration of wings, the fields of air are open to knowledge, and only ignorance and idleness need crawl upon the ground." This fanciful prophecy has almost been realized in fact.

Over one thousand aeroplanes have successfully flown, covering an aggregate distance of at least 150,000 miles. The inscrutable Sphinx has seen the aeroplanes of to-day pass and re-pass, majestic in the exactness and ease of their flight. Chavez, in one of the most daring flights ever made, crossed over the chasms and snow-covered peaks of the Alps. Exploits, almost as thrilling, have been performed by a score of other aviators; the Pyrenées, the Irish Channel, and the Hudson River, are but a few of the scenes of well-executed achievements, and aeroplanes have been flown under weather conditions that, formerly, would have been considered prohibitive.

Throughout the past year aviators have exhibited consummate skill, as well as a courage that was often foolhardy, in mounting higher and higher, until finally Hoxsey had attained the wonderful altitude of 11,400 feet. The sight of these human birds, hovering beyond the clouds, like Pascal's famous point, "in equilibrium in the infinite," is truly an impressive one.

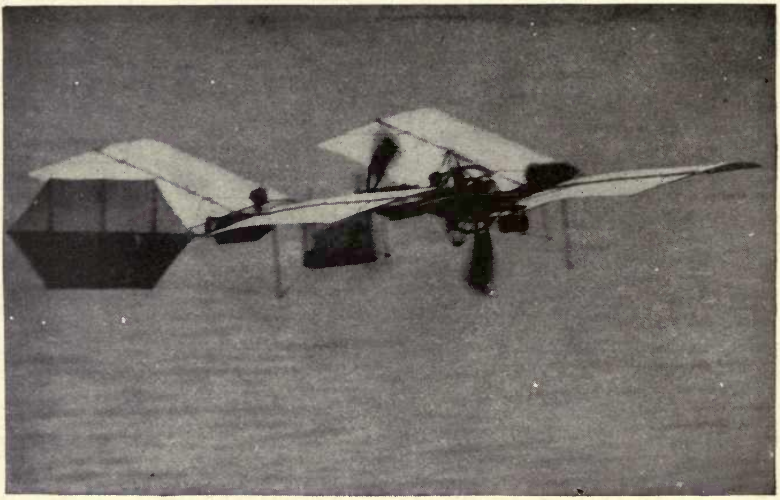
But in the active excitement of the present, the work of the early pioneers must not be lost sight of.

Langley, Lilienthal, and Chanute have contributed so largely and so well to the progress of aviation, that practical aeroplane designers of the present owe them a debt of gratitude that can hardly be repaid.

It is both interesting and appropriate to sum up the work done by these three great pioneers, and point out the effect their labors have had upon the highly successful efforts of the Wrights, Blériot, Levavasseur, and their contemporaries.

LANGLEY

It was in 1887 that Prof. Langley commenced his experiments in aerodynamics, the results of which led him to theoretical conclusions that are fundamental. Largely through the generosity of Mr. William Thaw, of Pittsburg, Prof. Langley was enabled to construct his famous "whirling table" at Allegheny, Pa. With the scientific thoroughness and exactness that had characterized his previous



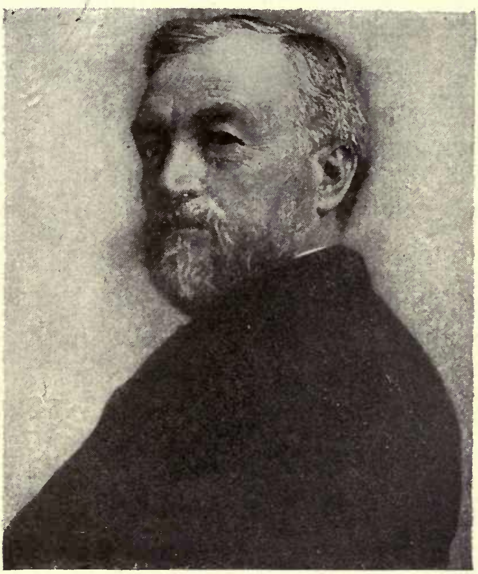
TELEPHOTO SNAPSHOT OF LANGLEY'S MODEL IN FLIGHT

The two propellers at the rear of the leading planes are seen in rotation, at either side of the motor. At the rear is another set of monoplane surfaces. The cruciform tail piece was practically automatic in its action and kept the machine on a straight course.

work in physics and astronomy, Langley set vigorously to work to investigate the problem of mechanical flight.

The "whirling table" consisted of a horizontal rotating arm, at the outer end of which were carried the surfaces, forms, and propellers that were to be tested. Almost all the results, of pressure, velocity, etc., were recorded automatically by means of ingenious electrical devices. The actual results of his experiments are referred

to in full elsewhere in this work, but it may be pointed out that, unquestionably, his greatest contribution to the knowledge on this subject was his thoroughly scientific verification of the fact, that the old Newtonian theorem on the pressure of air, experienced by a surface inclined at small angles, gave results that were almost twenty times too small. In addition, Langley investigated the well-

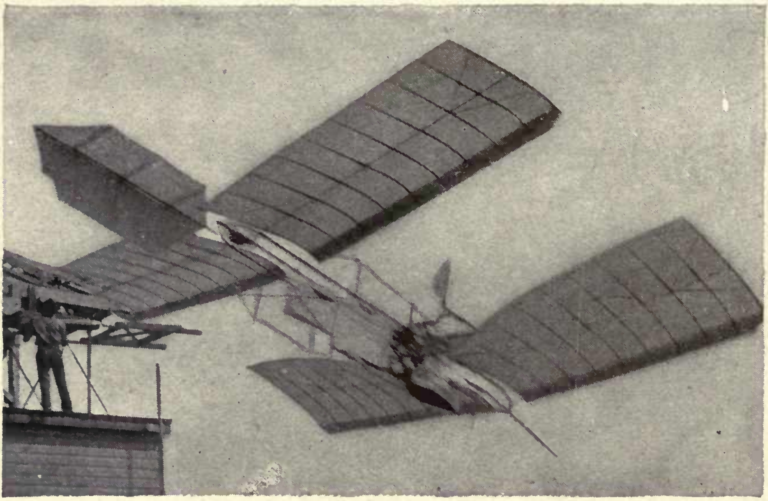


SAMUEL PIERPONT LANGLEY

known constant K, and obtained a value nearer the correct one than any of his predecessors. He also determined fully the variation in position of the center of pressure, the analysis of the total pressure on a surface into a lifting force and a resisting one, the effect of "aspect ratio," and other equally important and valuable matters; but inasmuch as these experiments were made on flat surfaces, their results have had little application to the design of the present-day aeroplane. Langley considered the actual friction of the air negli-

gible, and this is the only important characteristic of his work that is open to question.

Langley had an illustrious contemporary in Col. Renard, the builder of the first successful dirigible balloon, the "La France," who experimented exhaustively on planes, propellers and shapes of "least resistance" in his laboratory near Paris, and whose results to-day are of immense value to designers of dirigible balloons. Maxim, Kress, Dines, Phillips, and Hargrave followed Langley, and



FALSE START OF THE LANGLEY MAN-CARRYING "AERODROME" IN 1903
This machine was a faithful copy of the successful model.

contributed handsomely to the progress of aerodynamics, but it is in the character, and especially in the presentation, of his work that Langley stands out as the first and greatest pioneer.

In 1891, after the completion and publication of his "Experiments in Aerodynamics," Langley actively began the construction of flying machines. At first he experimented with models driven by rubber bands, but he found the flights too short and erratic to give any practical results.

His first steam motor-driven "model" aerodrome "No. 0," was then constructed, and was followed by "No. 1" and "No. 2," driven by compressed air and carbonic-acid gas motors. All of these failed because of the poor character of the motors. The next model, "No. 3," was built stronger and was more successful. The propellers were tested in the shop, being attached to a pendulum device. This pendulum, resting on knife edges, was prolonged

THE WRECKED "AERODROME" IN THE POTOMAC RIVER
The motor and some details of the framing are clearly shown here.

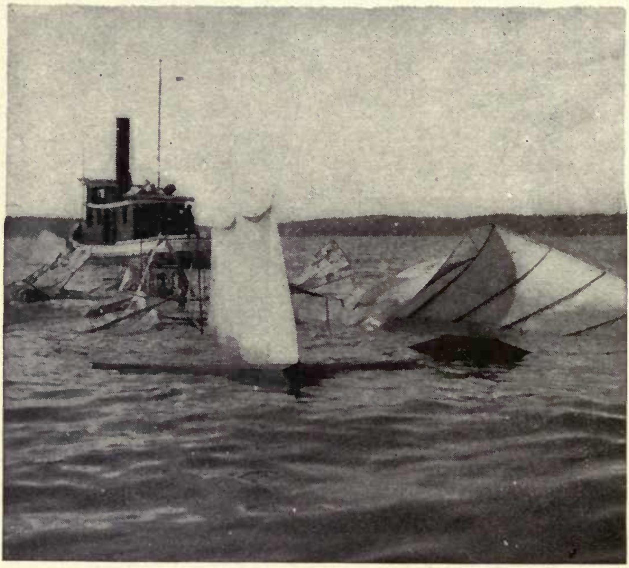
above the points of support, and was counterbalanced to give indifferent equilibrium. The propellers were so mounted that the line of thrust passed through the center of gravity, and when power was applied, they lifted the pendulum, thus enabling the dead-lift power of the engines to become known.

The engines of "No. 3" lifted 30 per cent of their own weight. "No. 4" was then built and taken to the Potomac on a house-boat,

to be extensively tested. Great difficulties were experienced in launching, and it was found that the upward pressure of the air deflected the wings, this minute difference causing the planes to act badly.

In 1894 and 1895 "No. 5" and "No. 6," stronger and better machines, were constructed.

Finally, on May 6th and November 28th, 1896, Langley's best



TOWING THE WRECKED "AERODROME" BACK TO THE HOUSEBOAT

model, driven by a 1 horse-power steam engine and weighing 27 pounds, was successfully flown several times; the best flight was over *three-quarters of a mile long,* and conclusively demonstrated the saneness and excellence of his work.

The United States government then made an allotment of $50,-000 to Langley for the construction of a man-carrying aerodrome, which was finally completed and tried on October 7th, 1903. This aeroplane, as can be seen from the photographs, consisted of two

sets of arched monoplane surfaces, with a central *fuselage* and a controllable cruciform tail very similar to that on the present Breguet biplane (see p. 163). The two propellers rotating in opposite directions were situated back of the front planes, and were driven by a light 50 horse-power steam engine, designed by Mr. C. M. Manley.

The machine would undoubtedly have flown had not an unfortunate breakage in the launching apparatus occurred, just as the aerodrome took to flight, causing it to lose its equilibrium and plunge downward into the water. Mr. Manley, who was on the machine, was rescued unhurt, but the aerodrome was so badly wrecked that no further experiments could be conducted with it. A section of the press then took a hostile attitude, and succeeded in discouraging Congress from any further appropriations. The public in general looked upon this wreck as conclusive evidence of the impracticability of Langley's work, and the brilliant investigator finally died three years later, broken in heart by the unjust criticisms of his noble efforts.

As aviation progresses, however, the great worth of his work becomes more and more manifest, and few now hesitate to give to him the enormous credit that is his due.

The effect of Langley's labor has been more pronounced on the theory of flight than on actual practice. The general lines of some of the French monoplanes, nevertheless, especially those with large lifting tails, closely resemble his machine, and one of M. Blériot's first successful monoplanes was a "Langley type."

LILIENTHAL

What Langley did to advance the aerodynamics of flat surfaces, Otto Lilienthal did for arched surfaces. But, in addition, this great German pioneer launched himself into the air on wings, and, from his personal experiences, laid down the first great laws of practical flight, as we know it to-day. The work of Lilienthal has without doubt had permanent effect on actual flying, and it is certain that without it we would not have progressed so fast.

The results of his experiments on arched surfaces, obtained by him in conjunction with his brother, after years of quiet scientific study and experiment, were published in 1889 in his monumental work "Der Vogelflug als Grundlage der Fliegekunst."

Lilienthal early recognized the importance of investigating the flight of birds, and the results of his experiments as well as the important discoveries he made are fully treated of later.

OTTO LILIENTHAL

To develop his theories and gain the experience he desired, Lilienthal constructed numerous gliding machines, 80 to 170 square feet in area, in which he launched himself into the face of the wind from the top of a mound of earth at Lichterfeld near Berlin. From a height of over 100 feet he glided down for a distance of 600 to 1,000 feet, landing gently at the bottom of the hill. In all he made over two thousand flights, and was the first man in the world to remain in the air on a heavier-than-air apparatus for any considerable length of time. He flew at first without any motive power, and succeeded in deviating his direction of

flight to the right or left merely by altering the position of his center of gravity by a corresponding movement of his legs, which were dangling freely from the seat. Later, as he became more and more expert in the art of keeping his equilibrium, he built and flew a double-deck machine equipped with a 2½ horse-power engine, by the aid of which he could feebly flap the wings, thus greatly extending the lengths of his glides. At this promising stage, August, 1896, an unexpected calamity removed him from

Lilienthal in Free Flight on His Biplane Apparatus, Showing the Character of the Framework and Shape of the Planes, as well as the Rear Tail Piece

The equilibrium was preserved by the swinging of the legs.

his sphere of work. While testing a horizontal steering arrangement fixed on an old and well-worn machine, he suddenly fell from a height of 50 feet, and broke his spine, a tragic martyrdom which later impressed so forcibly the two ingenious Wright brothers of Dayton, Ohio, that they resolved to follow in his footsteps, and if possible perfect the flying machine. In 1896 Pilcher in Eng-

land, and Herring in America, built Lilienthal type gliders and flew them successfully.

Lilienthal's greatest contribution to the advance of flight was his suggestion and proof of the fact that "as a due preparation for eventual human flight, practice in gliding flight, without the use of a motor, constitutes the best beginning."

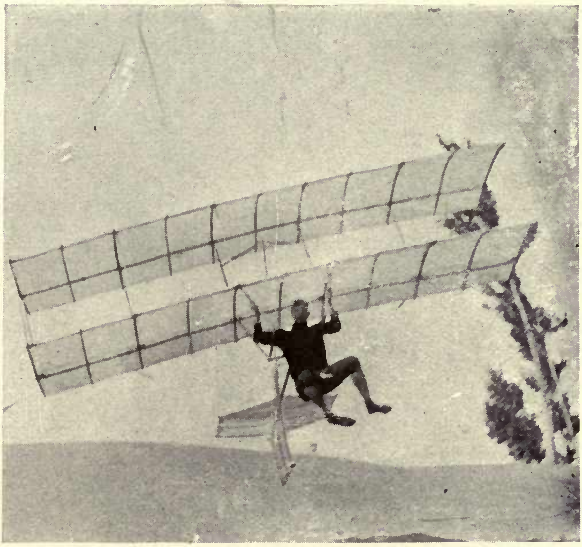
CHANUTE

Octave Chanute, who early achieved a remarkable reputation in his profession of civil engineering serving at one time as Chief Engineer of the Erie Railroad, turned his attention to the problem of flight in his later years. In 1894 Chanute contributed to the literature on the subject his interesting work, "Progress in Flying Machines," about the most complete historical treatise on aviation ever written. He concluded from his investigations that equilibrium was the most important problem to solve, and suggested that the simplest way to obtain it was by movement of the surfaces, and not of the man.

Inspired by the example of Lilienthal, he began to experiment in 1896, and the first machine to be tried out on the shores of Lake Michigan was a Lilienthal type, built by his assistant, Mr. A. M. Herring, who had already experimented with two similar machines. After about one hundred glides had been made, the equilibrium was found so precarious and so difficult to control that the machine was pronounced dangerous and discarded. A month later Lilienthal's sad death came to confirm this decision. About the same time a "multiple-winged" machine was tested in about three hundred glides. On this machine the planes could be made to swing to and fro horizontally, thus enabling the position of the center of pressure with respect to the center of gravity to be changed. After a few more experimental machines, the famous Chanute "double-decker" was constructed and successfully tested. This machine was the direct prototype of the present-day biplane, and embodied in its construction for the first time the bridge truss of wood braced by steel wires which is to-day so

widely used. Some seven hundred glides were made with this apparatus, and it is of immense importance to point out that not the slightest accident occurred during any of Chanute's experiments.

Before the end of the century Chanute's experiments were



CHANUTE GLIDER STRUCK BY A SIDE GUST; THE BODY SWINGING OVER TO THE RIGHT SIDE (OF THE PHOTOGRAPH) TO RESTORE EQUILIBRIUM

taken up by the Wright brothers, to whom he freely gave his assistance and valuable advice. In the summers of 1900 and 1901 the Wrights proceeded to follow the suggestion of Lilienthal that practice is the key to the secret of flying, and in the numerous glides executed at Kill Devil Hill, North Carolina, they gradually, and with infinite skill, made themselves masters of the air. The early Wright gliders greatly resembled the Chanute machines in construction, but differed in that a movable elevation control was placed in front, and the wings were made warpable

for transverse control. The aviator lay prone on the lower plane, thus materially reducing head resistance.

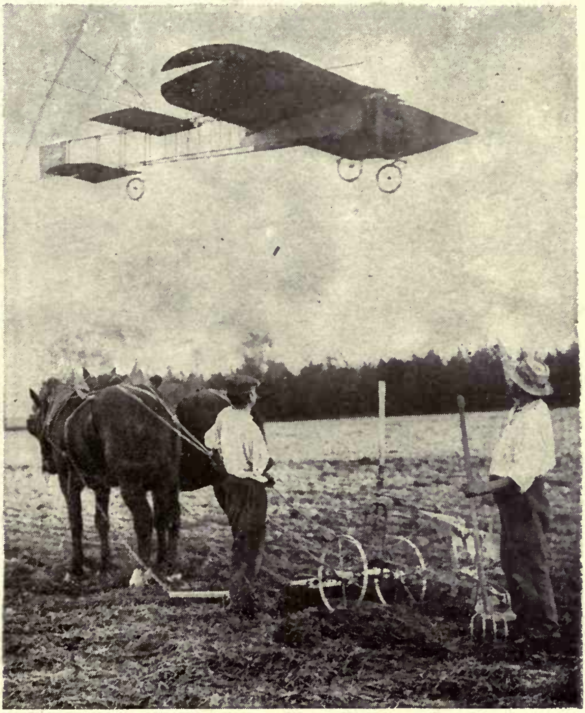
Finally on December 17th, 1903, the first prolonged motor-driven aeroplane flights were made. The machine used at this time

THE HERALD OF A NEW ERA
A Wright aeroplane in flight at dawn.

by the Wrights measured 40 feet in spread, weighed 700 pounds with the operator, and was equipped with three propellers, two at the rear and one below the plane to assist in lifting. The propellers were driven by a four-cylinder 16 horse-power gasoline motor weighing 152 pounds. The speed attained in the four short

flights made was about 30 to 35 miles per hour, and the longest time in the air was 59 seconds.

All during 1904 short practice flights were made at Dayton, often resulting in more or less serious breakages. On October 14th, 1904, three flights of over 4,000 feet were made.



BLERIOT DRIVING THE "NO. VIII TER," ON HIS 18-MILE TRIP FROM TOURY TO ARTENAY, FRANCE, OCT. 31, 1908

The movable ailerons and the rudders at the rear are shown in this photograph.

Another machine was built in 1905, embodying several improvements suggested by the practice of preceding years. Finally on October 5th, 1905, the Wright biplane flew a distance of 24 1/5 miles in 38 minutes. The world hesitated to believe that such

a thing was possible, and for a long time the Wrights were regarded skeptically by many people. The stimulating effects that Chanute's experiments and help had on the work of the Wrights, as well as the adoption by them of his bridge-truss type of construction, are unmistakable.

About this time, abroad, Archdeacon, Blériot, Pelterie, and Ferber, following also in the steps of Chanute, conducted various

FARMAN IN HIS EARLY VOISIN BIPLANE, MAKING THE FIRST CIRCULAR FLIGHT IN EUROPE, JAN. 13, 1908

gliding experiments. On August 22nd, 1906, Santos Dumont, by the aid of a remarkably light motor designed by Levavasseur, made the first motor flight in Europe. France went characteristically wild with enthusiasm, placing little confidence in the reported exploits of the Wrights. At once the Voisins, with Farman and Delagrange, began the development of their machines, and Louis Blé-

riot, with an admirable audacity and industry, built and smashed monoplane after monoplane until he had evolved the highly successful "Blériot VIII.," the first monoplane in the world to make extended trips.

The astonishing progress in aviation was on, and as it rolls and grows in size like the proverbial ball of snow, we should pause and reflect upon the immense value of the work of Langley, Lilienthal, and Chanute.

CHAPTER II.

The Resistance of the Air and the Pressure on Normal Planes

Although the fact that air has inertia is a familiar one, the important deductions to be drawn therefrom, were not fully recognized until the classic experiments of Langley exhibited them in their true import.

The resistance of the air in its bearing upon aeronautics, and especially in the consideration of the pressure on the surface of an aeroplane, is of fundamental importance.

Many values and methods of determining air resistance have been suggested, but they differ widely from each other. Because of this, designers of aeroplanes experience great difficulty in calculating the probable performance of their machines. A small difference in the value of the "constant of air resistance" may mean an over or under estimation of a certain pressure to the extent of several pounds, which in turn may involve added expense and decreased efficiency.

It is therefore desirable to investigate the present knowledge on the subject, not so much for the purpose of theoretic discussion as to arrive at some definite and conclusive values of the various quantities involved, that will be of use to the engineer.

The resistance of the air is directly proportional to its density. The density of the air varies with (1) temperature, (2) pressure, and (3) its state of equilibrium.

An increase of temperature causes air to expand, and therefore the density diminishes. Roughly, the density of the air varies inversely by 0.36 per cent for a difference of 1 deg. C.

At sea level in our latitudes and at 0 deg. C. 1 cubic foot of air

weighs very nearly 1½ ounces if the pressure is at 760 millimeters of mercury. But this pressure decreases as the height above sea level increases, and also at any point is subject to great variations due to meteorological conditions. A difference in pressure of 7.6 millimeters causes a direct variation of the density of about 1 per cent. At 20 deg. C. a difference in height of 340 feet above sea level gives a difference of 10 millimeters in the pressure. At a height of about 18,000 feet, for instance, the density of the air is exactly one-half of that at sea level.

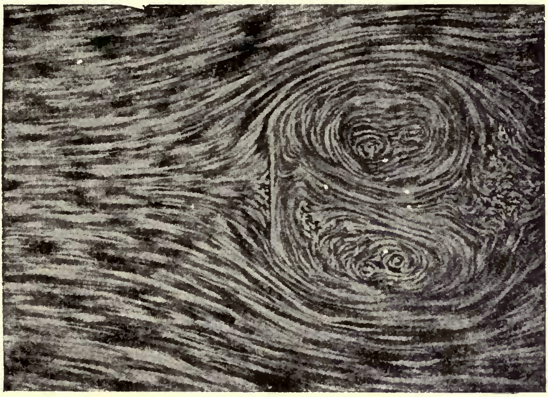
It is only recently that the effect of the condition of equilibrium

An Instantaneous Photograph by Prof. Marey, Showing the Action of an Air Stream Passing a Normal Surface from Left to Right

Note the whirls and regions of discontinuity and the compression of the air stream in front of the surface. These marvelous photographs were obtained by admitting thin streams of smoke into the air current.

of the air at any one point upon the density has been considered. The temperature and the pressure in a certain region remaining constant, a gusty wind and several buildings, etc., being in the neighborhood, there would be large variations in the density at different points. The disturbances and eddies set up by normal planes, spheres and spindles, are clearly shown in the accompanying stream line photographs. Even an aeroplane with an arched surface will, if the speed is high enough, leave a region of high density below and in its wake, and a region of low density above and in its wake. Everywhere in the atmosphere, and especially on windy days, there exist "pockets" of high density and of low density, sometimes large enough to completely immerse a full-sized aero-

plane. Very often the nature of a country is such that, when the wind comes from a certain direction, a region of low density always forms at some particular point. Abroad at the Rheims aerodrome, and here at our flying grounds at Mineola, such points actually exist, always about in the same place, and are called by the aviators "air holes." An aeroplane entering one of these low-density regions from the air of higher density around it, will suddenly fall without any warning, merely because the pressure has



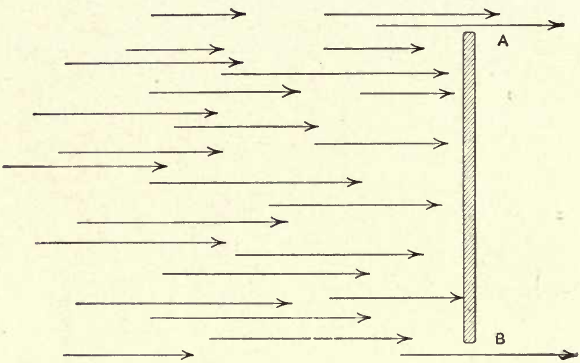
THE ACTION OF A STREAM OF WATER PASSING A NORMAL SURFACE FROM LEFT TO RIGHT. (AHLBORN)

enormously decreased, and the aeroplane has not had time to attain the requisite velocity of support in this lighter medium. Then again, when the machine after this experience passes into the heavier surrounding air, the shock due to the suddenly increased pressure is likely to cause a straining of some part, and a possible breakage. Whenever considering the air in which an aeroplane is flying, we must never lose sight of the fact that this fluid is irregular and unstable in its flow, subject to the most intricate movements and treacherous to the last degree.

The density, therefore, varies greatly, and directly affects the pressures on an aeroplane. In the summer, on a dry clear day, the

high temperature causes a low density, and the pressure is light, so that the aeroplane experiences the least resistance, and therefore at this season travels at a higher speed. On the other hand, in winter, with "snow in the air," the density is greatest, thus enabling the aeroplane to carry a much heavier load. Altitude will tend to give a speed increase, and rainy weather an increase of weight-lifting capacity.

Whatever value of air resistance is laid down, consequently, must be taken with reserve, as it is subject to very wide variations.



NEWTON'S IDEA OF THE ACTION OF THE AIR

The particles of air striking directly against a surface placed normal to the air stream, AB representing a section of the surface.

Values of air resistance vary also with the form of the body, and some shapes called "shapes of least resistance," "fusiform," or "stream line form," often experience only half the resistance of an equivalent, flat surface, placed normal to the air current. Only flat normal surfaces are considered here because they give the maximum resistance.

Sir Isaac Newton, in Section VII, Bk. 11, of the Principia, treats "of the motion of fluids, and the resistance made to projected bodies." He defines air as an elastic, non-continued, rare medium, consisting of equal particles freely disposed at equal distances from each other.

Thus if we represent by A B the section of a surface against which a stream of air is flowing, then the particles of air, according to Newton, impinge directly against the surface, as indicated by the small arrows in the diagram on p. 20.

In contrast to this Newton defines water, quicksilver, oil, etc., as continued mediums, where all the particles that generate the resistance do not immediately strike against the surface. The surface is pressed on only by the particles that lie next to it, which particles in turn are pressed on by the particles beyond, and so on. The diagram below shows the character of this fluid pressure.

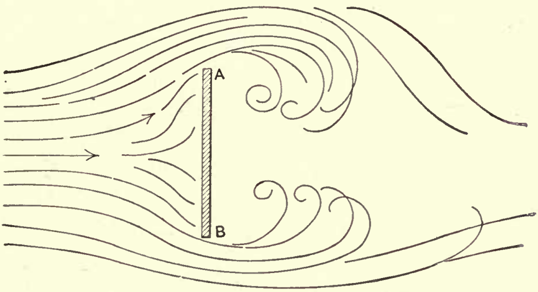


Diagram of the Flow of Air Around a Normal Surface AB

The subsequent experiments of Bernouilli, Euler, Robins, Borda, Bossut, and De Buat showed the imperfection of the first Newtonian theory. That air as a medium is similar in character to water is shown conclusively by the accompanying photographic results of the experiments on stream lines of air by Marey.

The resistance of a "continued" medium of this sort, according to Newton, is in the "duplicate ratio of the velocity" and directly as the density of the medium.[1]

Navier derives a similar relation.[2]

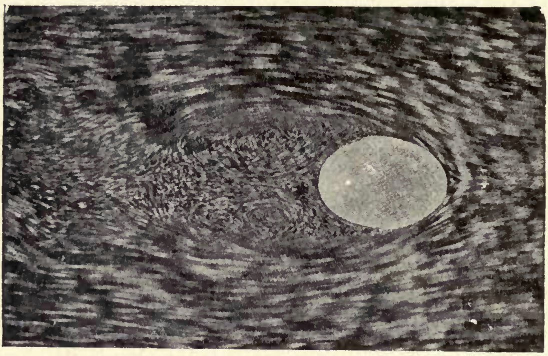
Robins in 1746, with a view to determining the resistance of the air to cannon balls, whirled planes and spheres about a circular orbit, and found that the resistance varied directly as the square of the velocity.

In 1791 Col. Beaufoy carried on a series of experiments, the results of which were published later in connection with the Swedish tests of Lagerhjelm in 1811. and showed also that the pressure varied as the square of the velocity.[3]

Rennie in 1830 abundantly verified this relation for low velocity and it can be accepted as true.[4]

In other words, if we express by P the pressure on a normal surface of area S, generated by an air stream of velocity V, then

$$P = K\ S\ V^2 \dots\dots\dots\dots (1)$$



THE FLOW OF WATER AROUND AN ELLIPTICAL PRISM FROM RIGHT TO LEFT. (AHLBORN)

where K is a constant of figure involving the density of the air and depending on the barometric pressure, the temperature and the character of the surface and usually termed the "constant of air resistance."

This equation may be derived from the laws of mechanics.

If we let W=the weight of air directed against any normal surface in a given time; w=the weight in pounds of one cubic foot of air; V=the velocity of the air stream in feet per second; S= the area of the surface on which the pressure acts; M=the mass of air of weight W; g=the acceleration due to gravity=32.2 feet per second[2]; and P=the pressure on the area S.

Then $W = w\ S\ v$

The momentum of the force on the area $= M\,v = \frac{Wv}{g} = \frac{w}{g} S\,v^2$

If $S=1$ square foot; $w=0.0807$ pounds per cubic foot for 32 deg. F. and 760 millimeters barometric pressure; and V be expressed in miles per hour, then since $P=M.v$

$P = .0054\ V^2$

K thus taking the theoretical value 0.0054, where V is expressed in miles per hour and P in pounds per square foot. This system of units will be used throughout this discussion.

In 1759 John Smeaton, in discussing some experiments of Rouse, deduced the formula $P = 0.005\ S\ V^2$, and considering S unity he published a table of the velocity and pressure of wind, as given here.[5] The correct Smeaton value for K is 0.00492, but it has become customary in engineering practice to take it as 0.005.

Smeaton adopted this table in his paper on "Mills" from his friend Rouse without any explanation of the kind of experiments from which it had been formed.

Rouse had based his results on a statement by Mariotte, which he verified by his own experiment consisting of whirling a 3 square foot plane in a circular orbit of only 30 feet circumference and at a maximum velocity of 8 miles an hour. Rouse assuming that the resistance varied as the square of the velocity, laid down the law that $P = 0.005.\ V^2$.

SMEATON'S TABLE

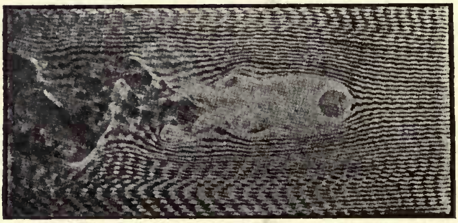
Velocity, Miles per Hour	Pressure, Lbs. per Sq. Ft.	Velocity, Miles per Hour	Pressure, Lbs. per Sq. Ft.
1	.005	40	7.873
2	.020	45	9.963
3	.044	50	12.30
4	.079	55	14.90
5	.123	60	17.71
10	.492	65	20.85
15	1.107	70	24.10
20	1.968	75	27.70
25	3.075	80	31.49
30	4.429	100	49.2
35	6.027		

Smeaton, although misinformed as to the experiments of Mariotte, proceeded to make use of these results and of the constant 0.005 and without any experiments of his own, formulated the well-known Smeaton Table (see p. 23), which appears as standard in the engineering textbooks of all countries.

Bender, in a thorough review of the whole subject, says that Smeaton's table is certainly unreliable.[6]

Hutton in 1787, using a whirling apparatus similar to that used by Robins, deduced the value of K as 0.00426.

The experiments of Didion on falling plates of 11 square feet area in 1837 established K=0.00336, and later experiments by him, the results of which were published in 1848, showed con-



AIR FLOWING FROM RIGHT TO LEFT PAST A CIRCULAR PRISM (MAREY)

This is precisely the character of the disturbance caused by a rod or steel tube on an aeroplane.

clusively that the resistance of the air was directly proportional to the square of the speed.[7]

Col. Duchemin in 1842 conducted experiments on the resistance of fluids which are in many ways remarkable. He investigated the subject very thoroughly and his work is standard. The value of K he derived as 0.00492.[8]

Poncelet, who also did much work in this line, obtained the value of K=0.00275.[9]

Hagen in 1860 obtained the value K=0.00292, and Recknagel in 1886 got the value 0.00287.[10] These experiments were all thorough, and the surfaces were moved in a straight line.

Thibault in 1856 and Goupil in 1884 derived K=0.0053.

Lord Rayleigh also considered the subject theoretically and deduced $K = 0.0055$.[12]

Experiments similar in character to the recent ones of Eiffel were conducted in 1892 by Cailletet and Collardeau and K was found to be 0.0029.[13]

Dr. Pole in 1881 deduced $K=0.0025$, and at some length discussed the absolute unreliability of Smeaton's table.[14]

Langley in his experiments with the rolling carriage in 1888 obtained values of K ranging from 0.00389 to 0.00320.[15]

Col. Renard of the French army, the builder of the famous dirigible "La France," carried out extensive experiments on planes and shapes of "least resistance" in 1887, and deduced the value of $K=0.00348$.[16]

Canovetti in the elaborate experiments conducted by him on inclined railways at Brescia and Brunate in Italy during 1901, determined the value of K as 0.0029.[17]

The most recent and complete experiments on the resistance of the air were conducted by Eiffel in 1903 and 1905. He recognized two sources of inaccuracy—the neglect of the consideration of the separate air filaments which vary at different points on the surface, and the cyclonic motion of the air, due to a revolving source. The experiments were conducted on the Eiffel tower, and the surface was attached to a carriage by springs, the pressure being recorded on a blackened cylinder. The carriage was allowed to fall vertically about 312 feet, and was constrained in its motion by a vertical cable.

The coefficient K varied remarkably little and was practically determined as 0.0031.[18]

Many other values of K have been determined.

Prof. Allen Hazen in 1886 deduced $K=0.0034$.[19]

Dines in 1889 obtained the value 0.0035.[20]

Lilienthal[21] and Von Loessel[22] determined K as 0.13 in metric units or 0.005 in English units.

In 1890 C. F. Marvin at Mount Washington, N. H., where it is said winds as high as 100 miles per hour were observed, got K as 0.004.

T. E. Stanton determined K for small surfaces at 0.0027.[23]

The Voisin brothers, builders of the famous biplane, derived a value of $K=0.0025$.[24]

The Wrights in 1901 conducted experiments on small planes and got the value of K as 0.0033.

Other formulæ than the one now so generally in use (formula I) have been suggested.

Canovetti lays down for unit surfaces the empirical formula: $P=0.0324\ V^2+0.432\ v$ (in metric units) as a result of his experiments.[25]

Experiments conducted by Morin, Piobert, and Didion in France about 1837 indicated that

$$P = 0.0073 + 0.0034\ V^2$$

THE AIR FLOW PAST A CIRCULAR SECTION, UNDER DIFFERENT LIGHT

The bright regions indicate high pressure and the dark regions as at the rear of the section indicate rarefaction.

Soreau in 1902 proposed a formula which for small velocities shows the pressure to vary as the square of the velocity and for higher velocities as the cube.[26]

Renard had previously pointed out that the general formula

$$P=K\ S\ V^2$$

was bad for either very low or very high velocities.[27]

Zahm, in measuring projectile resistances, found the pressure to vary as the cube of the velocity for high speeds.[28]

Eiffel found that between 18 and 40 meters per second the pressure was proportional to the square of the velocity, and at speeds above 33 meters per second it already began to increase and vary

as the cube. It is hardly probable, however, that aeroplanes will ever reach velocities where the pressure will vary other than sensibly as the square.

Interesting experiments conducted by A. R. Wolff showed that K for 45 degrees Fahr. was equivalent to Smeaton's value, that at 0 deg. Fahr. it was 10 per cent greater, and at 100 deg. Fahr. 10 per cent less.[29]

Langley, in considering the effect of temperature on density, expresses the relation between pressure and velocity for unit surface in the form,

$$P = \frac{KV^2}{1+0.00366(t-10\text{ deg.})}$$

where 0.00366 is the coefficient for expansion of air per degree C., t=temperature of the air in degrees C., and K is expressed for 10 deg. C. in metric units.

Prof. Kernot in experiments conducted on the Forth Bridge found the average pressure on large surfaces such as railway coaches, houses, etc., never exceeded two-thirds of that upon a surface of 1 or 2 square feet.[30] The variable density of air puffs, whirls, etc., would account for this, and probably the maximum intensity of pressure is confined to small areas.

Borda, Hutton, and Thibault found from their researches that the resistance increased with the absolute size of surface, while Dines holds a contrary opinion. Von Loessl's experiments showed that small and large surfaces experience resistances simply proportional to their sizes.

Eiffel found that K increased with the surface, but this increase was less and less as the size increased, and tended toward a maximum of 0.0033.

Soreau, after investigating the subject, gives it as his opinion that K may vary slightly with increase of size, but in the necessary approximations that are made in aeroplane design such variation would be negligible.

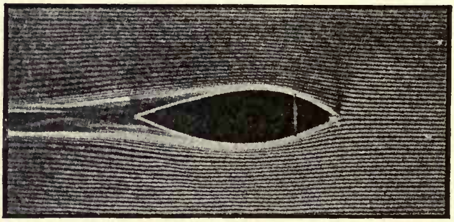
Most of the experiments cited thus far have been conducted on planes and shapes of very small size, and show large discrepancies.

The method of experimenting by use of a whirling table is

unquestionably inaccurate, because the air in the vicinity of the apparatus is itself set in a rotating motion.

Many of these results, therefore, because of the inadequate character of the apparatus used cannot be conclusively applied to the case of an aeroplane in flight.

Those experiments conducted in a straight line, however, more nearly resemble the actual conditions, and it need hardly be pointed out that the character of the air resistance to a fast moving train resembles much more the resistance experienced by a full sized aeroplane in flight, than any other of the methods used.



THE AIR FLOWING BY A STREAM-LINE FORM, SHOWING THE GREATER EVENNESS OF FLOW, AND THEREFORE DECREASE OF RESISTANCE

Numerous and excellent experiments on the resistance to trains have been conducted.

Mr. Scott Russell as early as 1846, in discussing the resistance of the atmosphere to trains, stated that the results of his experiments showed that the pressure according to Smeaton's Table was almost double the actual pressure on a plane and that the formula $P = 0.0025\ S\ V^2$ was correct.[31]

In 1901 J. A. F. Aspinall in experiments on trains carefully measured the air resistance by pressure gages and found $K = 0.003$. In his paper on this subject previous experiments are discussed very thoroughly, and in the fifty-five different formulæ and experiments on the resistance to trains that he cites, the large majority of them make use of values of K below 0.003.[32]

The most recent and accurate results in this line are given by the experiments on air resistance conducted during the tests

of the high-speed electric trains on the Berlin Zossen Railway in 1903.[33]

The velocities attained were as high as 110 miles an hour, and the air resistance was carefully measured by an elaborate set of accurate pressure gages.

The results were plotted on a large chart and the mean value of the observations showed that

$$P = 0.0027\ S\ V^2.$$

These experiments are undoubtedly the most accurate and the best applicable to the actual conditions of a large body moving through the air at high speed, that have ever been conducted, and show conclusively that the values of air pressure as originally formulated by Smeaton are very seriously at fault.

There are then to be distinguished two main methods of determining K, one by a rotational apparatus, and the other by movement in a straight line.

In the following tables experiments according to these two systems are separately grouped, and the values given are weighted.

Table of Values of K as Determined by Rotating Apparatus

Name.	Year.	Value.
Rouse	1758	.00500
Hutton	1787	.00426
Duchemin	1842	.00492
Hazen	1886	.00340
Renard	1887	.00348
Langley	1888	.00389
Dines	1889	.00350
Lilienthal	1889	.00500
Marvin	1890	.00400
Loessl	1899	.00530

Mean value..............=0.004275

Mean weighted value.....=0.00421

Table of Values of K as Determined by Straight Line Motion

Name.	Year.	Value.
Didion	1837	.00330
Poncelet	1840	.00275
Russell	1846	.00250
Hagen	1860	.00292
Pole	1881	.00250
Recknagel	1886	.00287
Cailletet	1892	.00290
Canovetti	1901	.00290
Wright	1901	.00330
Aspinall	1901	.00300
Stanton	1903	.00270
Zossen	1903	.00270
Eiffel	1905	.00310
Voisin	1907	.00250
Mean value	=0.00285	
Mean weighted value	=0.00290	

according to the completeness of the experiments, the accuracy, the time, whether very old or very recent, and the size of apparatus used. Mean values, and weighted mean values are then obtained. It must be borne in mind that the object of this investigation is to derive a working value of K applicable to full sized aeroplanes, and therefore experiments conducted on large surfaces are weighted more than those on small ones.

Grouping these results three distinct values of K are arrived at:

(1) $K=0.0054$ (By theory).

(2) $K=0.0042$ (By rotational apparatus).

(3) $K=0.0029$ (By movement in a straight line).

For the purposes of calculations of pressures on an aeroplane value (3) is unquestionably the most correct one.

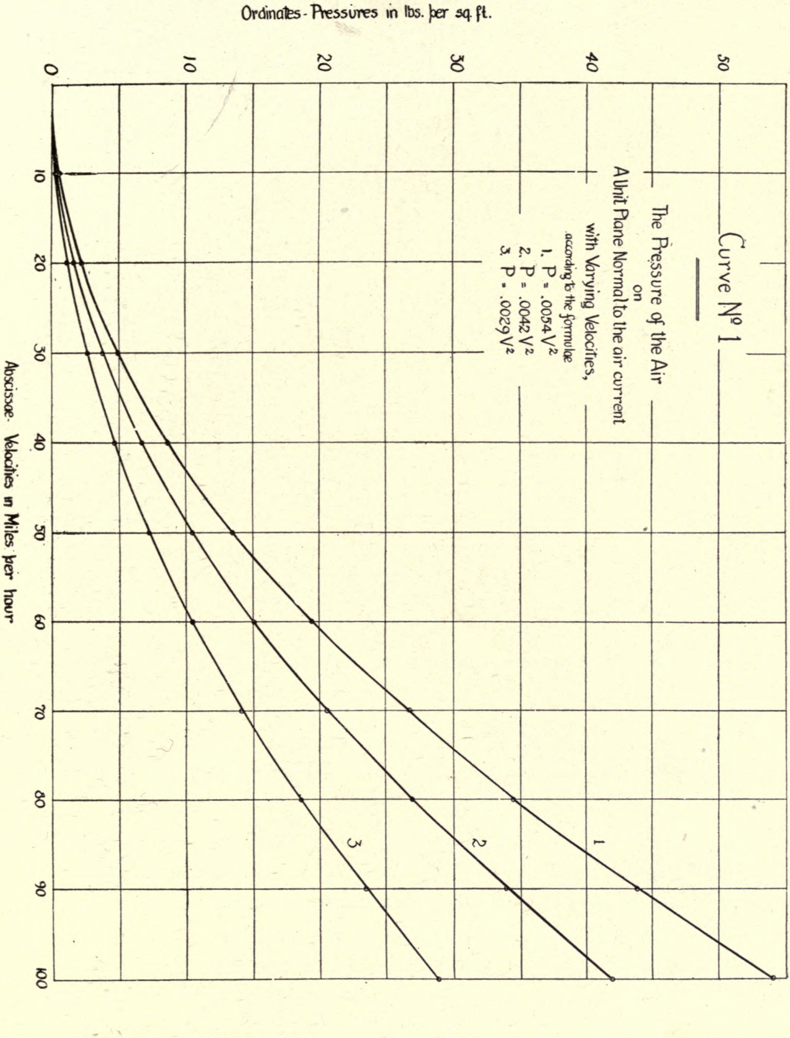
These results are graphically represented in Curve 1, which shows the great difference in the theoretical value of air resistance and value (3) very strikingly.

We may therefore conclude that for calculations of air pressure

as applied to aeroplanes, the most practical expression of such pressure is

$$P_{90} = 0.003\ S\ V^2$$

where $K = 0.003$, and P_{90} = the pressure on a surface of area S, normal to the air stream of velocity V.



An examination of stream-line photographs similar to those reproduced here, reveals distinctly the fact that the air stream directed against a normal surface is deflected at an angle, varying with the conformation of the surface. In the diagram below such a condition of air flow is shown in an exaggerated manner. This suggests a method of obtaining a rational value of K, by al-

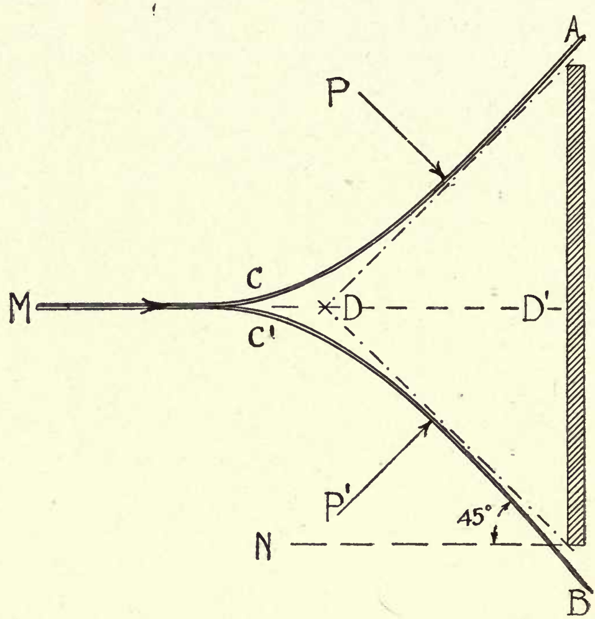


DIAGRAM SHOWING A POSSIBLE ACTION OF STREAMS OF AIR *MCA* AND *MC'B* ON A SURFACE *AB*

most the same process of mechanics as that used in deriving the value 0.0054 if the primary condition there, that the air is deviated at 90 deg. is discarded.

Instead, as we see by the diagram above, the air streams are deviated from their original horizontal direction to a direction $C'B$ or CA, at an angle $C'BN$, which in many instances of air-flow against a flat normal surface may be as low as 45 deg.

MCA and $MC'B$, the two filets of air when suddenly directed

against the surface *AB*, are likely to imprison a cushion of air *ADB*. The air stream presses on this air cushion along *DB* and *DA*, and causes it to transmit the pressure in all directions, as in any fluid. This means that there will be a compression in the air cushion itself along the region *DD′*, as well as a pressure on the surface itself. The moving air stream will therefore cause pressure *P* and *P′* to act normal to *DA* and *DB*, and in addition there will be a resistance due to the internal friction of the fluid along *DA* and *DB*. But in no case do we have a moving mass of air striking a surface at 90 deg. to its line of motion. The fact that the hypothetical surfaces *DA* and *DB* are at an angle of inclination means that the pressure exerted on them will be to the pressure considered previously for the 90 deg. normal condition (0.0054) as the sine of 45 deg. is to the sine of 90 deg., or roughly, as 0.71 to 1. Therefore instead of the theoretical value 0.0054 we would have $0.71 \times 0.0054 = 0.0038$, a value which certainly is much more reasonable.

This method is open undoubtedly to question, but is suggested here as a line of investigation that holds promise of bringing theoretical aerodynamics more easily in accord than any other with the actual results of experiment.

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[2] Navier, v. 11, Mem de l'Inst. de France.

[3] Beaufoy, "Nautical Experiments," London, 1834.

[4] Rennie, "On Resist. of Bodies in Air," Tran. Roy. Soc., 1831, p. 423.

[5] Chanute, "Progress in Flying Machines"; Rost, F., "Flugapparate"; Kent, p. 492.

[6] Bender, Proc. Inst. Civ. Eng., v. 69, p. 83.

[7] Didion, M., "Traite de Balistique," Paris, 1848.

[8] Duchemin, "Les Lois de la Resistance des Fluides."

[9] Poncelet, "Mecanique Industrielle," p. 601.

[10] Recknagel, "Uber Luftwiderstand," Zeit. Ver. Deut. Ing., 1886.

[11] Goupil, La Locomotion Aerienne, 1884.

[12] Rayleigh, "Resistance of Fluids," Phil. Mag., 1876.

[13] Cailletet and Collardeau, Comptes Rendus, 1892.

[14] Pole, Proc. Inst. Civ. Eng., v. 69, p. 205.

[15] Langley, "Experiments in Aerodynamics," p. 94.

[16] Renard, Ch., "Sur la Resistance de l'Air," Rev. de l'Aeronautique, v. 2, p. 31.

[17] Maleire, E., Genie Civil, v. 51, p. 245; Canovetti, C., Aerophile, v. 10, p. 140; Sci. Am., v. 96, p. 171.

[18] Eiffel, A. G., "Recherches sur la Resistance de l'Air," Paris, 1907; Comptes Rendus, v. 137, p. 30; Aerophile, v. 17, p. 5.

[19] Hazen, A., Am. Jour. Sci., v. 134, p. 241.

[20] Dines, Proc. Roy. Soc., v. 48, p. 252.

[21] Lilienthal, O., "Der Vogelflug, als Grundlage der Fliegekunst." Berlin, 1889.

[22] Ritter v. Loessl, F., "Die Luftwiderstand-gesetze." Vienna, 1895; Zeit. für Luft., v. 10, p. 235.

[23] Stanton, T. E., Proc. Inst. Civ. Eng., v. 156, p. 78.

[24] Voisin, G. and C., "Sur la valuer de K," Rev. de l'Aviation," August 15th, 1907.

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[26] Soreau, R., "Nouvelle loi de la Resistance de l'Air," Soc. des Ing. Civ., p. 464, v. 2, 1902.

[27] Renard, Ch., Sci. Am. Sup., v. 34, p. 13819.

[28] Zahm, A. F., "Resistance of the Air."

[29] Wolff, A. R., "The Windmill as a Prime Mover."

[30] Kernot, Eng. Rec., February 20th, 1894.

[31] Russell, Scott, Proc. Inst. Civ. Eng., v. 5, p. 288.

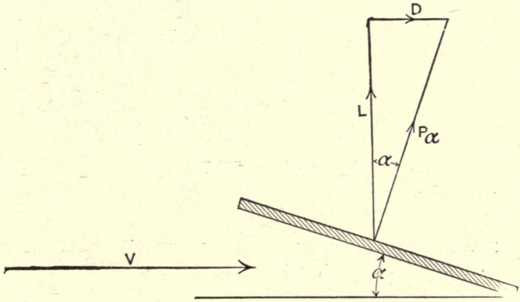
[32] Aspinall, J. A. F., "Train Resistance," Proc. Inst. Civ. Eng., v. 147, p. 155.

[33] Street Railway Journal, v. 19, p. 726.

CHAPTER III.

Flat Inclined Planes

If a thin flat plane is inclined at an angle a above the horizontal (diagram on this page), and if this plane is then placed in a current of air moving at a velocity V, as indicated by the arrow, the air stream will generate a force P_a in the surface tending to move it in the direction shown on P_a (which direction is always perpendicular to the plane when flat surfaces are used).



The Forces on a Flat Plane in an Air Current of Velocity V, and Set at an Angle of Incidence a

D is overcome by the thrust of the propeller. L, the lift on the planes supports the weight. P is the total effect of the air pressing on the surface as it passes by it.

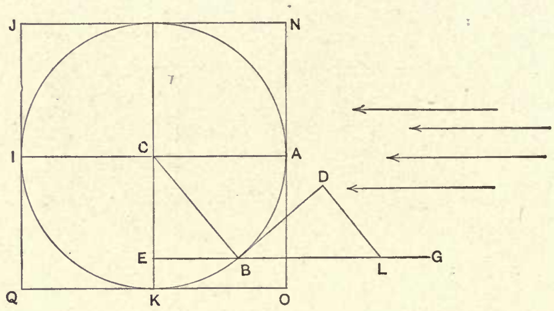
In Chapter II, the pressure P_{90}, acting on a surface placed normal to the air stream was defined and its value KSV^2 explained. When the plane is inclined, this pressure then called P_a is greatly reduced and varies with the angle of inclination. It is most convenient to express P_a as some part or function of P_{90}. The ratio of P_a/P_{90} then is a numerical quantity, by which P_{90} is multiplied to obtain P_a.

The relation of the pressure of a fluid on an inclined face to that

on a normal face was first investigated by Newton in Prop. XXXIV, Bk. II. of his "Principia," and he treats of the subject in the following manner; see diagram on this page.

Let $ABIK$ represent a spherical body with center C. Let the particles of the medium impinge with a given velocity upon this spherical body in the direction of right lines parallel to AC. Let GB be one of these right lines.

In GB take LB equal to CB and draw BD tangent to sphere at B. Upon KC and BD, let fall the perpendiculars BE and LD. Then a particle of the medium impinges on the globe at B in an



NEWTON'S THEOREM ON THE PRESSURE EXERTED BY AIR AGAINST AN INCLINED SURFACE

oblique direction. Let this force with which it would strike the globe be F. A particle of the medium impinges on the face of the cylinder $ONJQ$ described about the globe with the axis ACI, in a perpendicular direction at B. Let this force be F^1.

Then $F : F^1 = LD : LB = BE : BC$.

The force F tends to impel the globe in direction BC, normal to BD. Let this tendency be T. And let the tendency of the force to move the globe in direction parallel to AC be T^1.

Then $T : T^1 = BE : BC$.

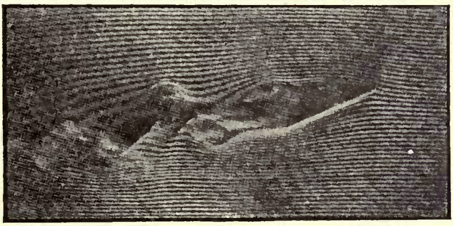
Then joining these ratios if we let P=the pressure exerted on the globe obliquely in the direction GB and P^1=the pressure ex-

erted on the face of the cylinder, perpendicularly, in the line GB,

$$P : P^1 = BE^2 : BC^2.$$

But BE is the sine of the angle BCE, and therefore sine of angle LBD, which is the angle of incidence of an element of surface to the direction of the wind. We therefore have by the Newtonian theorem, that the pressure of a moving fluid on an inclined surface is proportional to the square of the sine of the angle between the surface and the current.

Navier and Weisbach also advanced this theory with the result that scientists of the highest repute deduced that mechanical flight was practically impossible.



ACTION OF AN AIR STREAM ON A FLAT INCLINED PLANE

The angle of incidence is the angle between this plane and the horizontal. The stream is flowing from right to left.

Actual experiment, however, shows that this is absolutely unfounded and that the pressure on an inclined surface varies substantially as the sine of the angle of incidence. The pressure on the inclined surfaces of aeroplanes in use to-day is over 20 times greater than Newton's theorem would indicate, and the difference is more pronounced, the smaller the angle.

The fundamental hypothesis of Newton, that the resistance of the air was due directly to the impact of the particles renders his consideration of this question invalid.

In the excellent stream line photographs of Prof. Marey, reproduced herewith, the character of the air streams about an inclined flat surface are distinctly noticeable, and of themselves refute any suppositon that air acts on such a surface di-

rectly by impact. In the detailed study of photographs of stream lines of air, there is no doubt an opportunity of really solving the many problems of aerodynamics, and any number of valuable conclusions can be drawn directly from them. For example, on close examination one is inclined to observe that any form of surface is continually surrounded by a thin film of air, and that the moving air stream never really comes in contact with the surface itself, at all.

In 1763 Borda conducted some experiments on flat inclined surfaces, and proposed a formula in which the pressure was made proportional to the sine of the angle of incidence.

Shortly after this, in 1788, Hutton measured the horizontal component of the pressure on inclined planes by means of a small whirling arm, and these experimental results showed distinctly that Newton's theory was at fault. Hutton deduced the ratio of resistance between inclined and normal planes where α = angle of inclination as $\sin \alpha^{1.842 \cos \alpha}$.

Col. Duchemin in 1842 proposed the formula:[1]

$$P_\alpha = P_{90} \frac{2 \sin \alpha}{1 + \sin^2 \alpha}$$

where P_α is the pressure acting on a plane inclined at angle α with the air current and P_{90} the corresponding pressure on the same plane when placed normal to the current as obtained by the formula:

$$P_{90} = KSV^2 \text{ (see Chapter II)}$$

Hastings proposed the formula:

$$P_\alpha = P_{90}\, 2 \sin \alpha$$

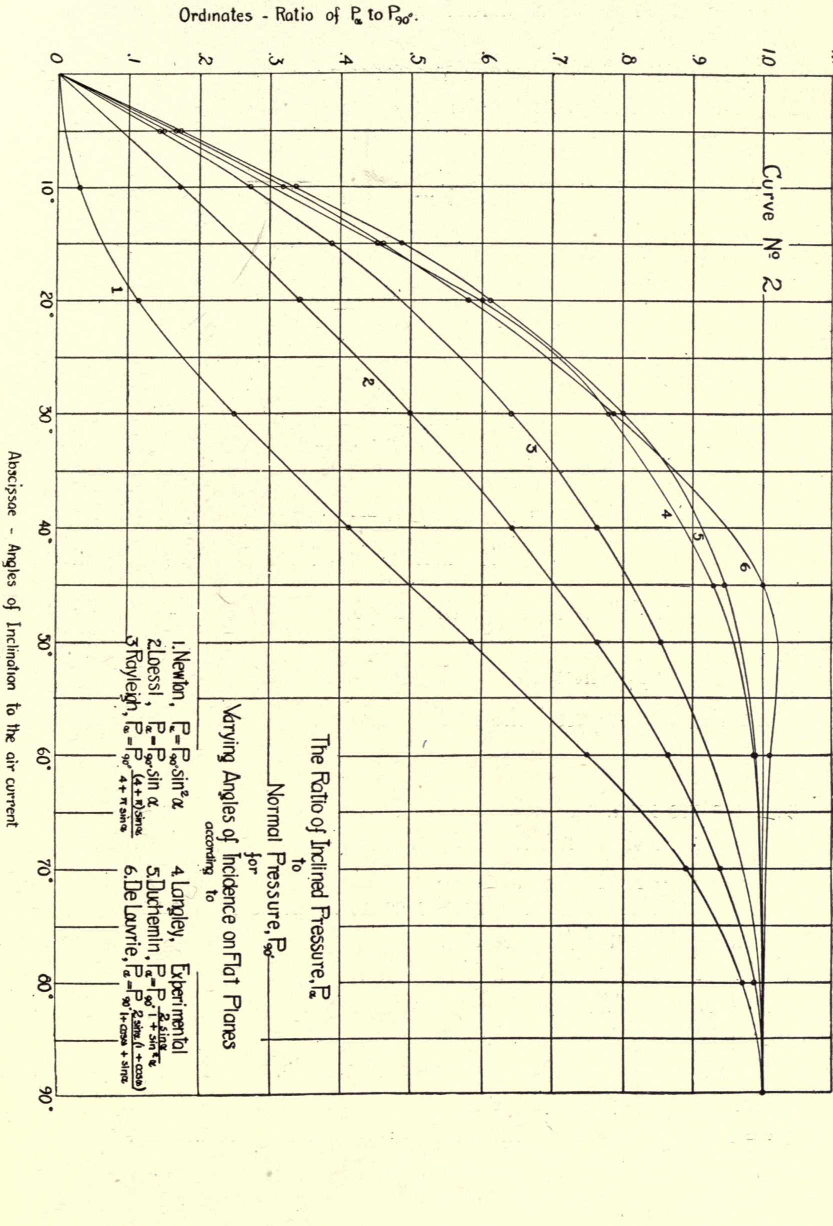
for small angles.

Lord Rayleigh, after investigating this problem[2], expressed the relation between P_{90} and P_α as

$$P_\alpha = P_{90} \times \frac{(4 + \pi) \sin \alpha}{4 + \pi \sin \alpha}$$

This formula was verified by Stanton in 1902.

Combining both theory and experiment in Von Loessl made the


Ordinates - Ratio of P_α to $P_{90°}$.
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1
Curve No 2
10° 20° 30° 40° 50° 60° 70° 80° 90°
1 2 3 4 5 6
The Ratio of Inclined Pressure, P_α
to
Normal Pressure, $P_{90°}$
for
Varying Angles of Incidence on Flat Planes
according to
1. Newton, $P_\alpha = P_{90°} \sin^2\alpha$
2. Loessl, $P_\alpha = P_{90°} \sin\alpha$
3. Rayleigh, $P_\alpha = P_{90°} \frac{(4+\pi)\sin\alpha}{4+\pi\sin\alpha}$
4. Langley, Experimental
5. Duchemin, $P_\alpha = P_{90°} \frac{2\sin\alpha}{1+\sin^2\alpha}$
6. De Louvrie, $P_\alpha = P_{90°} \frac{2\sin\alpha(1+\cos\alpha)}{1+\cos\alpha+\sin\alpha}$
Abscissae - Angles of Inclination to the air current

pressure on an inclined surface directly proportional to the sine of the angle of incidence.[3]

De Louvrie enlarging upon the formula of Duchemin, expressed P_α in terms of P_{90}[4], in the form:

$$P_\alpha = P_{90} \times \frac{2 \sin \alpha\, (1 + \cos \alpha}{1 + \cos \alpha + \sin \alpha}$$

Dorhandt and Thiesen proposed the formula:

$$P_\alpha = P_{90} \frac{2 \sin \alpha}{1 + \sin \alpha}\left(1 - \frac{0.62 \sin \alpha}{1 + \sin \alpha}\right)$$

Joessel's formula is:

$$P_\alpha = P_{90} \frac{\sin \alpha}{0.39 + 0.61 \sin \alpha}$$

and Goupil gives

$$P_\alpha = P_{90}\, (2 \sin \alpha - \sin^2 \alpha)$$

Eiffel, as a result of his earlier experiments (1907), obtained values that led him to adopt the simple formula $P_\alpha = P_{90} \frac{\alpha}{30}$ where $P_\alpha = 1$, when $\alpha = 30$ deg.

Luyties also suggests the formula:

$$P_\alpha = P_{90}\, (2 \sin \alpha - \sin^2 \alpha.)$$

which gives results almost identical with that of De Louvrie.[5] He further gives the convenient and accurate enough relation for very small angles, proposed by Eiffel.

A formula of substantially the same form as Hutton's was suggested by Soreau quite recently.[6]

Six of these various formulæ are graphically represented in Curve 2, the difference between the Newtonian formula and the others being quite marked.

This curve can be used precisely as a table. If, for example, we desire to determine the pressure on a flat plane, the area of which, $S = 10$ square feet, moving at $V = 30$ miles per hour, and inclined

at an angle $\alpha = 20$ deg., the pressure P_{90} is first computed.

$$\begin{aligned} P_{90} &= 0.003 \times S \times V^2 \\ &= 0.003 \times 10 \times 900 \\ &= 27 \text{ pounds.} \end{aligned}$$

From the curve we see that a reasonable value for P_α/P_{90} when $\alpha = 20$ deg., is about 0.6. Then:

$$\begin{aligned} P_\alpha &= 0.6\ P_{90} \\ &= 0.6 \times 27 \\ &= 16.2 \text{ pounds:} \end{aligned}$$

This is the total force acting on this surface under the assumed conditions.

Langley's experiments showed conclusively that the sine squared law was wrong. In the experiments with the resultant pressure recorder,[7] his results show a remarkably close agreement with the formula of Duchemin, as is shown by the accompanying Table. This practically identifies Duchemin's formula as correct for flat surfaces.

TABLE OF VALUES FOR

Ratio of $\dfrac{P_\alpha}{P_{90}}$, according to Langley and Duchemin

Angle of Inclination.	By Langley's Experiments.	By Duchemin's Formula.
5	.15	.17
10	.30	.34
15	.46	.48
20	.60	.61
25	.71	.72
30	.78	.80
35	.84	.86
40	.89	.91
45	.93	.94

We can therefore conclude for flat surfaces that

$$P_\alpha = P_{90} \frac{2 \sin \alpha}{1 + \sin^2 \alpha}$$

where $P_{90} = .003\ SV^2$.

LIFT AND DRIFT

If we represent by P_a (see diagram on p. 35) the pressure acting perpendicular to the surface of a flat plane, inclined at an angle α in a wind current of velocity V, we may resolve it into two components at right angles, one acting perpendicularly and equal to L, and another acting horizontally and equal to D.

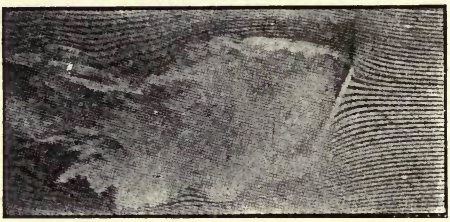
Then $D = P_a \sin \alpha$

and $L = P_a \cos \alpha$

This resolution was indicated by Sir George Cayley as early as 1809.

It is not purely theoretical, however, but has been verified by Langley's experiments as well as by actual practice.

In the present terminology of Aerodynamics we call L the "lift"



A Flat Plane at a High Angle of Incidence Impeding the Air Flow from Right to Left

and D the "drift" of a plane, L being the effective supporting force equal to the weight carried and D the dynamic resistance overcome by the thrust of the propeller.

The velocity of the aeroplane is directly dependent on the value of D, and as D decreases, the resistance to motion becomes less and consequently either the power necessary decreases, or a higher velocity can be obtained.

The ratio of these two quantities L/D, called the ratio of lift to drift, is obviously an excellent means of expressing the aerodynamic efficiency of an aerofoil, and is used as such.

Since one of the primary considerations in aeroplane design is to carry the greatest amount of weight at the highest velocity, or

conversely with the least expenditure of power, it is desirable to obtain as high a value for the lift L and as low a value for the drift D, as possible. In other words, we try to obtain a high value of L/D, the ratio of lift to drift.

In gliding flight, the higher the value of L/D, the longer will be the glide.

[1] Duchemin, "Les Lois de la Resistance des Fluides," Paris, 1842.

[2] Rayleigh, Lord, Manch. Philos. Soc., 1900; Nature, v. 27, p. 534; Smith. Inst. Rep., 1900.

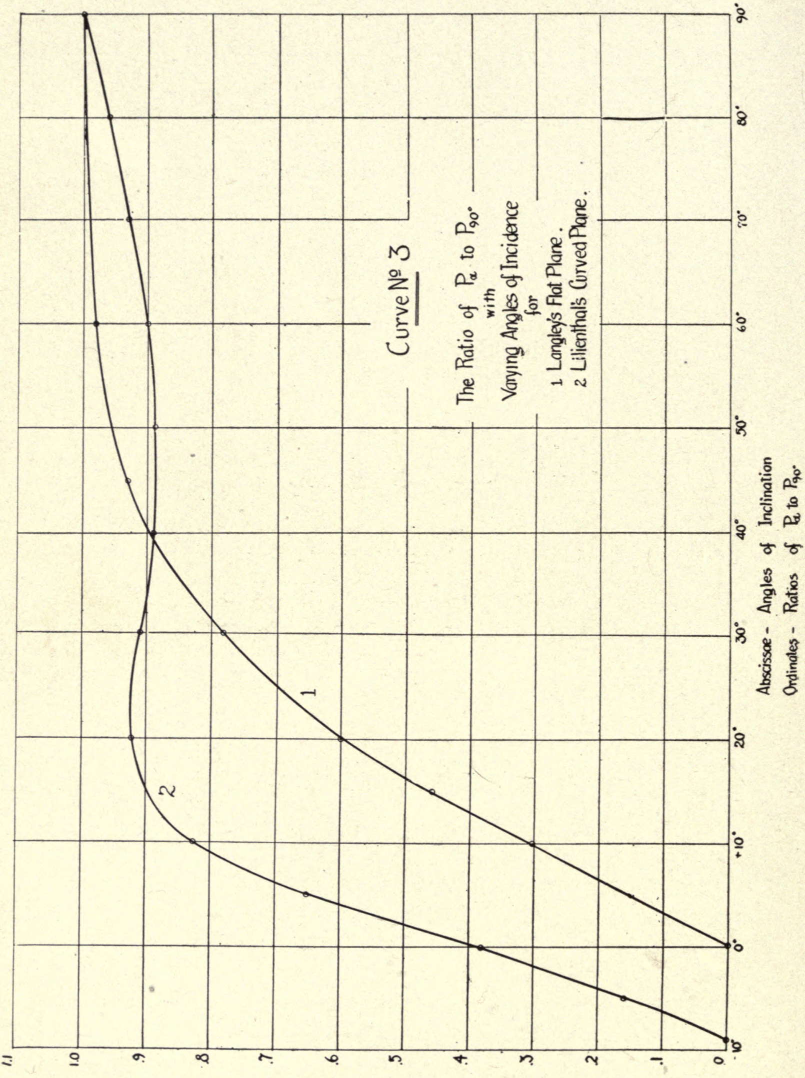
[3] Ritter von Loessl, "Die Luftwiderstandgesetze."

[4] De Louvrie, Ch., Proc. Int. Conference, 1893.

[5] Luyties, O. G., Aeronautics, v. 1, p. 13, No. 3.

[6] Soreau, R., "Nouvelle Formule," Aerophile, v. 17, p. 315.

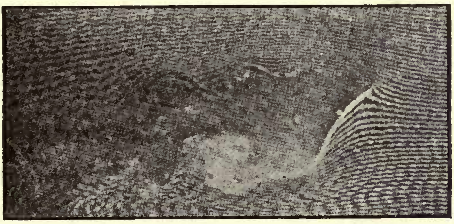
[7] Langley, "Experiments in Aerodynamics," p. 24.


Curve No 3
The Ratio of P_α to $P_{90°}$
with
Varying Angles of Incidence
for
1 Langley's Flat Plane.
2 Lilienthal's Curved Plane.
Abscissae - Angles of Inclination
Ordinates - Ratios of P_α to $P_{90°}$
1
2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.
-10°
0°
+10°
20°
30°
40°
50°
60°
70°
80°
90°

CHAPTER IV.

THE PRESSURE ON CURVED PLANES

THE photographs of the stream lines about a curved surface set at a low angle of inclination to the line of flight bear full confirmation of its greater efficiency. In the photograph below is shown the condition of the air flow for an arched or curved plane, almost normal to the air stream, and the regions of low density, high density, and discontinuity appear similar to those for a flat plane. But when this curved plane is inclined only slightly above the horizontal as shown in the photographs on p. 48 and p. 51, the smooth-



AT HIGH ANGLES OF INCIDENCE A CURVED PLANE CAUSES AS GREAT A DISTURBANCE AS A FLAT ONE

ness of flow of the air stream past the surface becomes strikingly evident.

Langley it is said investigated curved surfaces, but his results have not as yet been published.

Lilienthal, striving to imitate the birds, examined carefully the shape and structure of wings of the various species.[1] He recognized the importance of the shape of wing and found after experiment that even very slight curvatures of the wing profile (in section) considerably increased the lifting power.

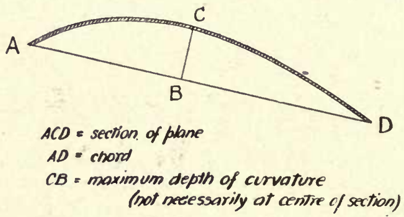
The arching of a surface is the same as its depth of curvature and is also sometimes expressed as its camber or cambered depth.

In the diagram below, if CB is 1/12 of the chord AD, then the surface shown in section has a depth of curvature of 1/12 chord.

In a flat plane the pressure is always perpendicular to the surface and as pointed out above, the ratio of lift to drift is therefore as the cosine to the sine of the angle of incidence.

But in curved surfaces a very different condition exists. The pressure is not uniformly normal to the chord of the arc, but is considerably inclined in front of the perpendicular at low angles with the result that the lift is increased and the drift is decreased.

Lilienthal was the first to discover this significant fact and fully set it forth. He says: "When a wing with an arched profile is



THE SECTION, CHORD, AND DEPTH OF CURVATURE OF A PLANE

"Depth of a plane" is the same as chord.

struck by the wind at an angle a with a velocity V, there will be generated an air pressure P which is not normal to the chord, but is the resultant of a force N, normal to the chord and of another force T, tangential to the chord."

These forces are shown in the diagram on p. 47. The air pressure P_a is precisely analogous to P_a for flat surfaces, in that it represents the total effective force of the air stream on the surface.

To determine N and T, Lilienthal conducted a series of experiments on planes shaped in plan somewhat like a bird's wing (not rectangular). He expressed N and T for the surface he used, 1/12 depth of curvature, as functions of P_{90}.

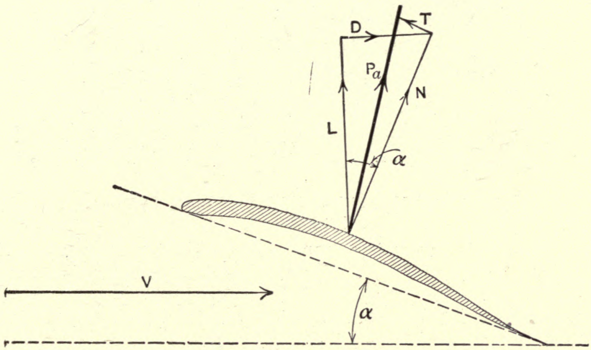
Thus $N = n \times P_{90} = n \times 0.003\ SV^2$

$$T = t \times P_{90} = t \times 0.003\ SV^2$$

where n and t are numerical quantites; $n = 1$, when $\alpha = 90$ deg. Lilienthal's results are given in the table on p. 49.

Values of n and t show that arched surfaces still possess supporting powers when the angle of incidence becomes negative. The air pressure T becomes a propelling one at angles exceeding 3 deg. up to 30 deg.

As Mr. Chanute pointed out, this does not mean that there is no horizontal component or "drift" of the normal pressure N,



THE FORCES ON A CURVED SURFACE, IN AN AIR STREAM V AT AN ANGLE OF INCIDENCE α

The forces are assumed to be acting through the center of pressure.

under these conditions, but that at certain angles the tangential pressure T, which would be parallel to the surface and only produce friction in the case of a flat plane, acts on a curved surface as a propelling force[2].

Thus if it was desired to find N and T for a surface 100 feet square, moving at 40 miles an hour and set at an angle of incidence of + 6 deg., the normal pressure P_{90} would first be computed.

$$P_{90} = KSV^2 = 0.003 \times 100 \times 1600$$
$$= 480 \text{ pounds.}$$

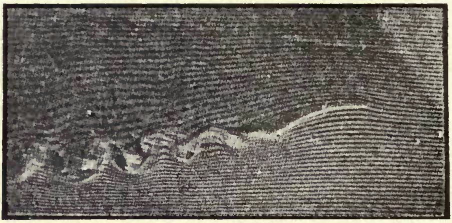
Then referring to Table (p. 49) we find that at + 6 deg. $n =$ 0.696 and $t = -0.021$.

Therefore $N = 0.696 \times 480 = 334$ pounds
and $T = -0.021 \times 480 = -10.1$ pounds.

Since its sign is negative T is a propelling force.

The force N is itself resolved into the components L and D as was done with P_a for a flat plane (see diagram p. 47).

It is to be observed, however, that T is inclined at an angle α above the horizontal. Therefore to obtain its effect as lift and



THE JUSTIFICATION FOR THE USE OF CURVED SURFACES

The air streaming from right to left past a curved plane, showing the great ease of flow. Compare with the action on a flat surface.

drift, it must be resolved into its vertical and horizontal components. These are

$$l = T \sin. \alpha$$
$$d = \pm T \cos. \alpha$$

The force l is almost negligible.

The total effective lift is then:

$$L' = L + l = (N \cos. \alpha) + (T \sin. \alpha)$$

and the total effective drift is:

$$D' = D \pm d = (N \sin \alpha) \pm (T \cos \alpha)$$

To complete the numerical example, sin 6 deg. = 0.105 and cos 6 deg. = 0.995.

Then $L' = (0.995 \times 334) + (0.105 \times 10.1) = 333.5$ pounds
$D' = (0.105 \times 334) - (0.995 \times 10.1) = 25.0$ pounds

In this manner we get the Lift and Drift of the assumed plane at a velocity of 40 miles an hour, according to the Lilienthal method. The ratio of lift to drift for this plane is 13.3.

The experiments of Wilbur and Orville Wright at Kitty Hawk

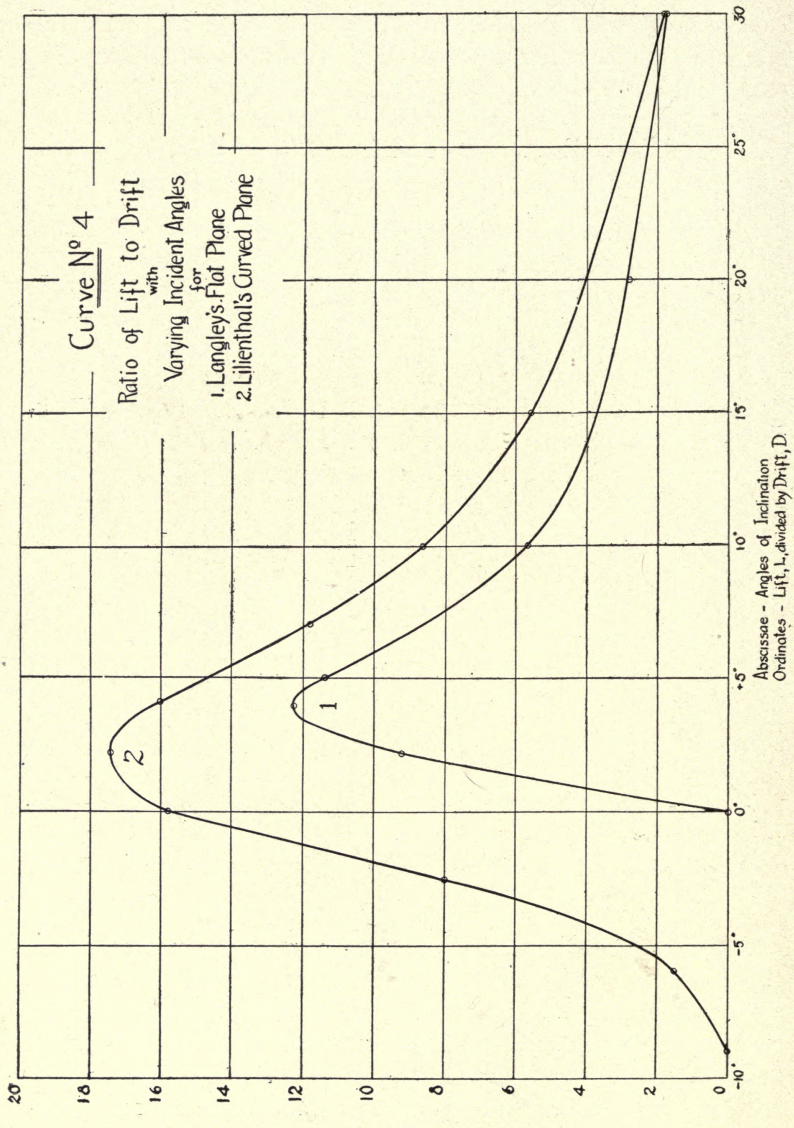
verified the existence of "Lilienthal's Tangential," and experiments conducted by them later in the laboratory further supported this fact, although their results were smaller than those of Lilienthal at angles below 10 deg.[3]

LILIENTHAL'S TABLE, 1/12 CURVE

α deg.	n	t	α deg.	n	t
— 9	.000	+.070	16	.909	—.075
— 8	.040	+.067	17	.915	—.073
— 7	.080	+.064	18	.919	—.070
— 6	.120	+.060	19	.921	—.065
— 5	.160	+.055	20	.922	—.059
— 4	.200	+.049	21	.923	—.053
— 3	.242	+.043	22	.924	—.047
— 2	.286	+.037	23	.924	—.041
— 1	.332	+.031	24	.923	—.036
0	.381	+.024	25	.922	—.031
+ 1	.434	+.016	26	.920	—.026
+ 2	.489	+.008	27	.918	—.021
+ 3	.546	.000	28	.915	—.016
+ 4	.600	—.007	29	.912	—.012
+ 5	.650	—.014	30	.910	—.008
+ 6	.696	—.021	32	.906	.000
+ 7	.737	—.028	35	.896	+.010
+ 8	.771	—.035	40	.898	+.016
+ 9	.800	—.042	45	.888	+.020
+10	.825	—.050	50	.888	+.023
11	.846	—.058	55	.890	+.026
12	.864	—.064	60	.900	+.028
13	.879	—.070	70	.930	+.030
14	.891	—.074	80	.960	+.015
15	.901	—.076	90	1.000	.000

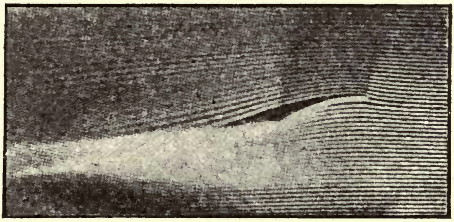
Curve 3 shows the variation of the normal pressure on an inclined plane according to Lilienthal (curved), and the same for a flat plane according to Langley. The difference especially for small angles, exhibits at once the greater lifting effect of curved surfaces.

In his experiments, it appears that Lilienthal did not realize


Curve No 4
Ratio of Lift to Drift
with
Varying Incident Angles
for
1. Langley's Flat Plane
2. Lilienthal's Curved Plane
1
2
20
18
16
14
12
10
8
6
4
2
0
-10°
-5°
0°
+5°
10°
15°
20°
25°
30
Abscissae - Angles of Inclination
Ordinates - Lift, L, divided by Drift, D

the full significance of the movement of the center of pressure or point of application of P_a, away from the center of surface (see p. 64). Accordingly his experimental values of n and t for low angles are far too great. For example, the Wrights, in an experiment conducted by them on a full-sized aeroplane, found that Lilienthal's estimate of the pressure on a curved surface having an angle of incidence of 3 deg. as equal to 0.546 of P_{90} was nearly 50 per cent too great.

Though many excellent treatises have been written on the subject, it is hardly possible with the present knowledge of aerodynamics to explain exactly what the significance of these pressures



THE CONDITION OF THE AIR STREAM FLOWING BY A CURVED PLANE

The dark region above the plane indicates rarefaction.

N and T are, or to bring them under any well-known set of physical laws.

Wegner von Dallwitz, however, has succeeded in arriving at a mathematical expression of the lift of a curved plane as

$$L = K \cos \alpha \tan^2 \alpha \, S.V^2$$

where K is a constant equal to 0.26 when metric units are employed.

The well-known theory of Soreau, in which a number of other constants than K are used, also gives fairly good results by analytical methods.

THE RATIO OF LIFT TO DRIFT

The ratio of Lift to Drift is, as we have seen, of great importance in the design of aeroplanes, and that surface which has the

greatest ratio of lift to drift, under working conditions, will be the most efficient from an aerodynamic standpoint, i. e., it carries the greatest weight with the least power.

Curve 4 shows the variation of this ratio with the incident angle for both Langley's flat plane and Lilienthal's arched one.

The difference is very pronounced, and the large values of the ratio for small angles show arched surfaces to be the most economical in flight, especially for soaring or gliding.

Curve 5 shows the variation of the ratio of lift to drift for various shaped surfaces experimented with by A. Rateau in Paris.[4] These experiments were carried on in a very complete manner, and their results are of great practical importance.

These experiments on the relation of sustaining power to head resistance, on various shaped planes, show that a thick curved plane is by far the most stable but not so very efficient. The Antoinette monoplane is equipped with surfaces of this kind.

That a high aspect ratio is of great consequence is shown very clearly by a comparison of the curves corresponding to types 2 and 3.

The variations of the ratio of L/D with aspect ratio and depth of curvature, however, are taken up in detail in Chapter VII; especial reference is made there to the experiments of Prof. Prandtl of Göttingen and M. Eiffel.

Rateau's values of L/D for his curved surface marked No. 3 (see Curve No. 5) are very high, compared to the Prandtl results (see curves Nos. 12, 13, 14).

The 1910 experiments of M. Eiffel on curved surfaces gave very interesting results.[5] In the table on p. 54 some of his values for a curved surface, 150 millimeters $\times$ 900 millimeters, and with a depth of curvature of 2/27 chord, are tabulated in both metric and English units.

M. Eiffel expresses drift as a constant Kx multiplied by SV^2, the usual value of K for P_{90} being included in the values for Kx. The same is done for lift. Obviously at 90 deg., the value of Kx equals the value of K, 00314 (see Chapter II).

Eiffel's values for lift are very high compared to those of Prandtl.

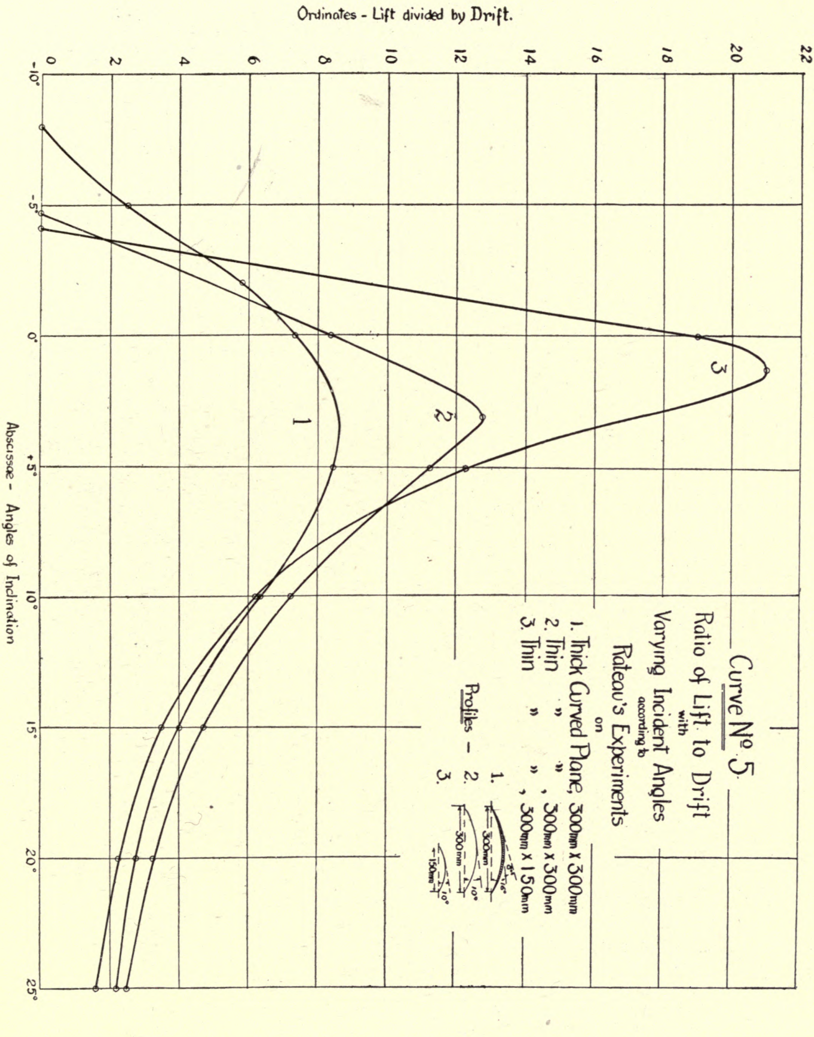

Ordinates - Lift divided by Drift.
0
2
4
6
8
10
12
14
16
18
20
22
-10°
-5°
0°
+5°
10°
15°
20°
25°
Abscissae - Angles of Inclination
1
2
3
Curve No. 5
Ratio of Lift to Drift
with
Varying Incident Angles
according to
Rateau's Experiments
on
1. Thick Curved Plane, 300mm x 300mm
2. Thin " " , 300mm x 300mm
3. Thin " " , 300mm x 150mm
Profiles - 1.
2.
3.
300mm
300mm
150mm
16°
10°
10°

TABLE OF LIFT AND DRIFT OF EIFFEL'S CURVED PLANE

Kx = Drift coef., Ky = Lift coef.

	In Metric Measures.		In English Measures.	
α	Kx	Ky	Kx	Ky
0°	.003	.033	.00012	.00137
5°	.006	.054	.00025	.00224
10°	.009	.072	.00037	.00298
15°	.017	.076	.00071	.00314
20°	.025	.067	.00104	.00278
30°	.034	.062	.00141	.00257
45°	.049	.051	.00203	.00212
60°	.063	.037	.00266	.00153
75°	.073	.020	.00303	.00083
90°	.076	....	.00314	......

Roughly K in metric measures ÷ by 24.1 = K in English measures.

As an example of the manner in which M. Eiffel's results are used, the same plane already employed to illustrate the Lilienthal method is used again, S = 100 square feet, and V = 40 miles an hour.

Hence $S.V^2 = 160{,}000$.

Referring to the Table on this page, it is seen that at 6 deg. the lift and drift coefficients are approximately 0.0024 and 0.00028, respectively.

Therefore,

$$\text{Lift} = Ky \times SV^2 = 0.0024 \times 160{,}000 = 384.0 \text{ pounds}$$
$$\text{Drift} = Kx \times SV^2 = 0.00028 \times 160{,}000 = 44.8 \text{ pounds}$$

values that are considerably higher than those of Lilienthal.

[1] Lilienthal, O., "Vogelflug als Grundlage der Fliegekunst" Zeit. für Luft., v. 14, heft 10; Aeron. Annual, No. 3, p. 95.

[2] Chanute, O., "Sailing Flight," Aeron. Annual, No. 3 p. 115.

[3] Wright, W., "Some Aeronautical Experiments," Smith. Inst. Rep. for 1902, p. 145.

[4] Rateau "Recherches Dynamiques," Aerophile, v. 17, p. 338.

[5] Eiffel, G., Soc. des Ing. Civ. de France, 1910; L'Aerophile, Feb. 1, 1910, p. 63.

CHAPTER V.

THE FRICTIONAL RESISTANCE OF AIR

It is well known, from the investigations of Froude and others, that the frictional resistance of a body in water was great. By analogy it would seem as if the friction of the air would also be considerable. Many prominent experimenters and investigators, however, have stated that the tangential resistance of air is negligible.

Langley implicitly assumed the effect of friction at the speeds he used, to be negligible, and did not investigate the problem to any extent.[1]

Clerk Maxwell conducted experiments on the viscosity of the air, i. e., the internal friction of the fluid, and gave the coefficient of viscosity of air as $\mu = 0.0001878\ (1 + 0.0027\ \theta)$, θ and μ being taken as defined in his paper.[2] By this formula the actual tangential force on a plane of one square foot area moving horizontally at 100 feet per second is less than 1/50 of 1 per cent of the pressure on the same plane when moved normally at this speed.

Maxim, Dines, and Kress considered the friction negligible throughout their experiments.[3]

Armengaud and Lanchester, who have thoroughly investigated the subject, take the opposite view and consider skin friction a very appreciable factor in the resistance of an aeroplane.[4]

Lanchester gives the total friction on both ends of a plane as 0.015 of the normal pressure. Thus the frictional resistance F of a flat plane 200 square feet in area, moving at 50 miles an hour, and set at an angle of 20 deg., would be

$$\begin{aligned} F &= 0.015\ (0.003 \times 200 \times 2500) \times (0.59) \\ &= 13.27 \text{ pounds} \end{aligned}$$

In 1882 Dr. Pole investigated the skin frictional resistance of the dirigible balloon of M. Dupuy de Lome and found it to be $0.0000477\ dlv^2$ where d is the diameter, l the length, and v the velocity.[5] This gave a very appreciable value to the frictional resistance.

W. Odell in 1903 conducted experiments for the purpose of determining the friction of the air on rotating parts of machines

and arrived at the conclusion that the energy dissipated per second $= c\ w^3\ v^5$ where c is a constant, w the angular velocity of the disks with which he experimented, and v the radius of the disk.[6] The friction was found to be considerable, although the character of his experiments precludes their being applied directly to aeroplanes.

Canovetti found the skin friction on surfaces equal to a constant times the square of the velocity, the constant taking the value 0.00012 when the metric system of units was employed.[7]

The most thorough experiments in this line were conducted by Prof. Zahm in 1903.[8] The results of his experiments showed conclusively that the friction of the air on surfaces was a very considerable factor, and he expressed its general value in the formula:

$$f = 0.0000158\ l^{0.07}\ v^{1.85}$$

where $f =$ the frictional drag in pounds per square foot, $l =$ the length of the surface in the direction of motion in feet, and $v =$ the velocity of the air past the surface in miles per hour.

The friction was found approximately the same for all smooth surfaces, but 10 to 15 per cent greater with extremely rough surfaces such as coarse buckram.

The table on page 58 gives Zahm's values for f as obtained by experiment and from the above formula. The frictional drag for any intermediate velocity or length of surface may readily be found by interpolation.

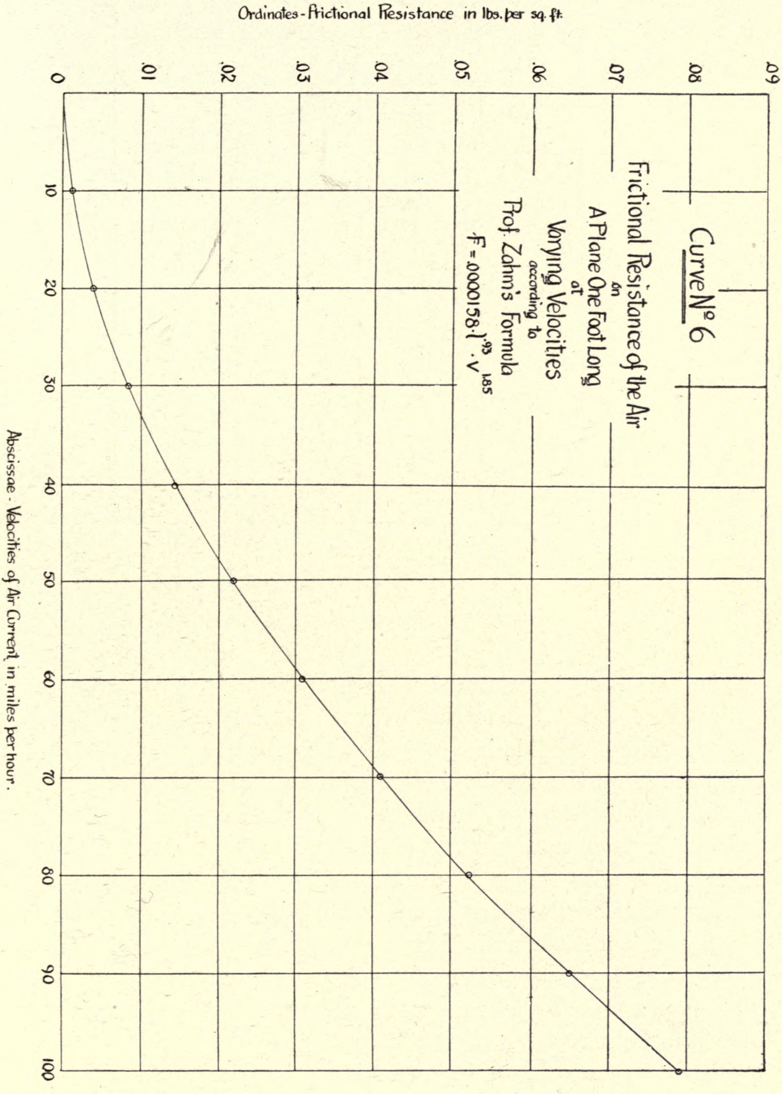
The frictional resistance of a flat or arched aeroplane surface of area S is

$$F = 2 \times f \times S$$

the factor 2 being introduced because the value of f refers to a single surface of a plane, while a plane in free flight has, of course, two sides exposed to frictional resistance.

To illustrate the practical application of these results on air friction, the actual frictional resistance F of a biplane consisting of two surfaces, 30 feet wide and 4 feet deep, moving at 60 miles an hour is computed, $S = 240$ square feet. From the table on page 58 the value of $f = 0.0279$.

$$\therefore F = 2 \times 0.0279 \times 240$$
$$= 13.4 \text{ pounds.}$$


Ordinates - Frictional Resistance in lbs. per sq. ft.
Curve No 6
Frictional Resistance of the Air
on
A Plane One Foot Long
at
Varying Velocities
according to
Prof. Zahm's Formula
F = .0000158 · l^.93 · V^1.85
0
.01
.02
.03
.04
.05
.06
.07
.08
.09
10
20
30
40
50
60
70
80
90
100
Abscissae - Velocities of Air Current in miles per hour.

Wind speed.	Average friction in pounds per square foot.			
	1′ plane.	2′ plane.	4′ plane.	8′ plane.
mi. hr.				
5	0.000303	0.000289	0.000275	0.000262
10	0.00112	0.00105	0 00101	0.000967
15	0.00237	0.00226	0 00215	0.00205
20	0.00402	0.00384	0.00365	0.00349
25	0.00606	0.00579	0.00551	0 00527
30	0.00850	0.00810	0.00772	0.00736
35	0.01130	0.0108	0.0103	0.0098
40	0.0145	0.0138	0.0132	0.0125
50	0.0219	0.0209	0.0199	0.0190
60	0.0307	0.0293	0.0279	0.0265
70	0.0407	0.0390	0.0370	0.0353
80	0.0522	0.0500	0.0474	0.0452
90	0.0650	0.0621	0.0590	0.0563
100	0.0792	0.0755	0.0719	0.0685

Skin Friction Table (Zahm)

This value is very much less than what would be obtained by using Lanchester's method.

The frictional resistance of air as determined by Zahm bears a striking resemblance to that of water as determined by Froude.[9] Froude found the friction to vary very nearly as $v^{1.85}$, and a comparison of the results indicates that the resistances are proportional in some way to the densities of the two media.

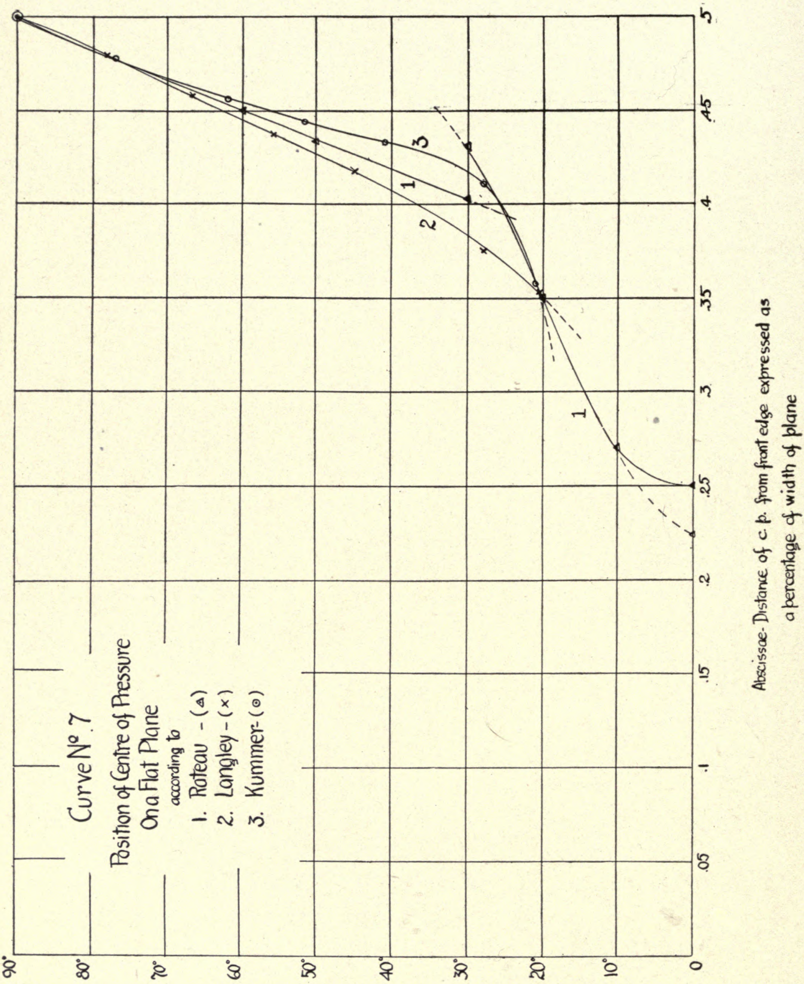
If it is true that the air stream never touches an aeroplane surface but only comes in contact with the air film surrounding it, then the frictional resistance would be the same for all reasonably smooth surfaces, but would be higher for surfaces so rough that the fibers themselves cause regions of discontinuity. This appears to be borne out in the results of the experiments of Prof. Zahm.

Curve 6 shows the variation of the skin friction on a unit surface with speed as plotted from Prof. Zahm's tables.

It is now generally accepted that skin friction is an appreciable

factor in the resistance of an aeroplane, and amounts in an average sized machine to from 10 to 25 pounds.

[1] Langley, S. P., "Exp. in Aerodynamics," p. 9.
[2] Maxwell, Clerk, Phil. Trans., v. 157.
[3] Baden-Powell, Aeronautics (Brit.), v. 1, p. 117.
[4] Lanchester, F. W., "Aerodynamics"; Armengaud, "Probleme de l'Aviation."
[5] Pole, William, Ecl. Eng. Mag., v. 27, p. 1, 1882.
[6] Odell, W., "Experiments on Air Friction," Engineering (London), January, 1904.
[7] Canovetti, "Sur la Resistance de l'Air," Paris, Acad. Sci., v. 144, p. 1030.
[8] Zahm, A. F., "Atmospheric Friction," Bulletin, Phil. Soc. of Wash., v. 14, p. 247.
[9] Froude, Brit. Assoc. Report, 1872.


Curve No. 7
Position of Centre of Pressure
On a Flat Plane
according to
1. Rateau - (△)
2. Langley - (×)
3. Kummer - (⊙)
90°
80°
70°
60°
50°
40°
30°
20°
10°
0
.05
.1
.15
.2
.25
.3
.35
.4
.45
.5
1
2
3
Abscissae - Distance of c. p. from front edge expressed as
a percentage of width of plane

CHAPTER VI.

THE CENTER OF PRESSURE ON FLAT AND CURVED PLANES

In unsteady winds the center of pressure on an aeroplane moves about greatly, and tends, by its variation in position, to upset the equilibrium, so that the efforts of many experimenters, noticeably Alexander Graham Bell, have been directed to the construction of an aeroplane in which the movement of the center of pressure is made very small. On a small tetrahedral cell the movement is very light, and probably one of the greatest advantages in the Bell "compound tetrahedral" structure is that the resultant center of pressure shifts to no greater extent than for one cell itself. This tends to give an unusual stability to the entire structure.

Newton implicitly assumed that when a rectangular plate was moved through the air at an angle of inclination to the line of motion, the center of pressure and the center of the surface were always coincident. It has long been recognized, however, that this is not the case, and that the position of the center of pressure varies with the incident angle.

Joessel, in 1869, was the first to experimentally determine the variation of position of the center of pressure at different angles.[1] His experiments were conducted on square flat planes and he deduced as a result of his experiments the formulæ:

$$C = (0.2 + 0.3 \sin \alpha)\ L$$
$$d = (0.3 - 0.3 \sin \alpha)\ L$$

where C is the distance of the center of pressure from the front edge of the plane, α is the angle of incidence, L is the width from front to back of the plane, and d is the distance of the center of pressure from the center of surface. These formulæ indicate that the center of pressure varies from 0.5 to 0.2 of the distance from the front to the center of the plane.

In 1875 Kummer also conducted experiments on the position

of the center of pressure.[2] The method of experiment adopted by him consisted essentially in finding the angle of inclination of the plane, corresponding to a series of fixed distances of the center of pressure from the center of figure.

The experiments conducted by Langley with the "counterpoised eccentric plane"[3] were also of this character. Both of these sets of experiments were on flat square planes, and their general results given in the table on this page show how closely they agree.

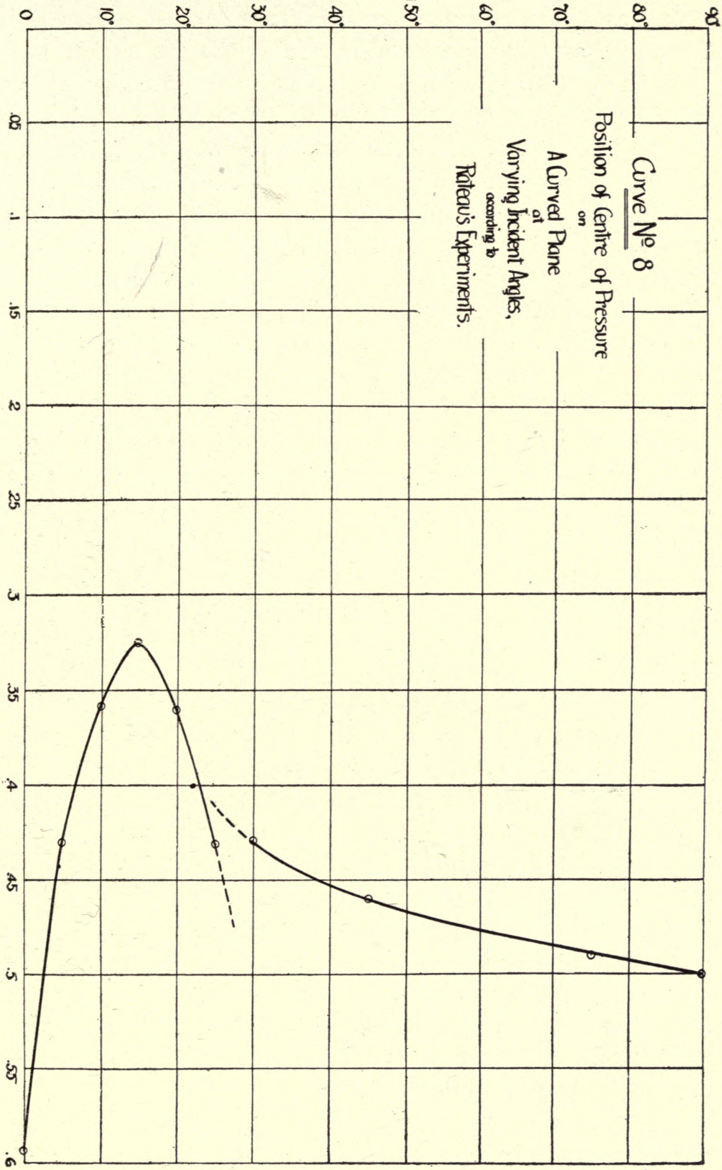
POSITION OF CENTER OF PRESSURE

Angle of plane with current.	Distance of c. p. from center of plane as percentage of side of plane. Langley.	Kummer.
90 deg.	0	0
78 deg.	.021	
77 deg.		.022
67.3 deg.	.042	
62 deg.		.044
55.8 deg.	.063	
52 deg.		.056
45 deg.	.083	
41 deg.		.067
28 deg.	.125	.089
21 deg.		.144
20.5 deg.	.146	

Neither of these experimenters obtained values for very low angles.

M. Rateau, in the aerodynamic experiments recently conducted by him, investigated the variation of position of the center of pressure on flat planes.[4] His results are shown graphically in Curve 7, and indicate that at 0 deg. and near 30 deg. there are regions of great instability. The results of Langley and Kummer are also plotted on this curve for comparison.

The movement of the center of pressure on curved surfaces is quite different from that on flat surfaces.



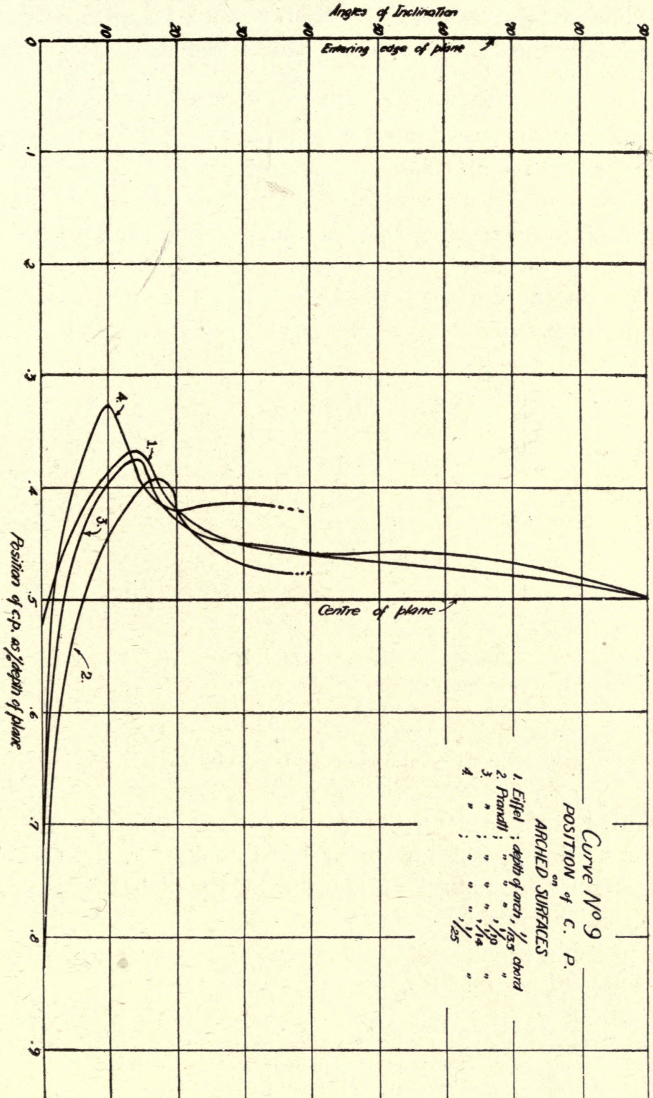
Abscissae - Distance of c.p. from front edge as % width of plane.
Ordinates: Angles of Inclination of Plane to Air Current.

In deeply arched surfaces the center of pressure moves steadily forward from the center of surface as the inclination is turned down from 90 deg. until a certain point is reached, varying with the depth of curvature. After this point is passed a curious phenomenon takes place: the center of pressure instead of continuing to move forward with decrease of angle, turns rather abruptly and moves rapidly to the rear. According to Mr. Wilbur Wright, this action is due largely to the pressure of the wind acting also on the upper side of the arched surface at low angles. The action, however, is unmistakable, and has often been observed in practice.

The experiments of M. Rateau, already alluded to, also included an investigation of the movement of the center of pressure on an arched surface, the results of which are shown graphically in Curve 8. The reversal in movement is very apparent in the neighborhood of 15 deg. and shows strikingly how different the conditions of pressure on a curved surface at low angles are from those on flat surfaces. A region of instability at 30 deg., however, seems also to be present in this curved surface.

The 1910 Eiffel experiments on the curved surface, 900 millimeters $\times$ 150 millimeters, already referred to, included a determination of the movement of the center of pressure. The results are given in graph No. 1, on curve sheet No. 9. A reversal at about 15 deg. is here observed, but the backward movement is not as pronounced as in the Rateau determination.

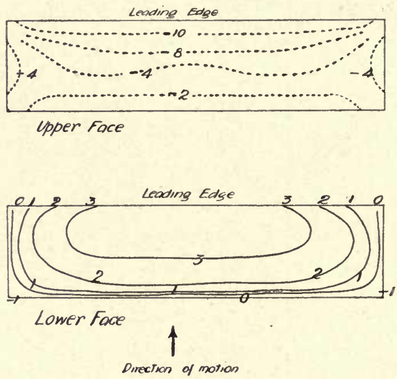
On curve sheet No. 9 are also given the results of the experiments of Prof. Prandtl,[5] on planes of different curvature. These show that as the depth of curvature is decreased the reversal point moves farther forward, and in addition, the reversal takes place at a lower angle and more suddenly. The backward movement, however, is greatest for the deepest curved surface (1/10). The results lead to the conclusion that because of the greater suddenness of reversal, very slightly curved surfaces are more dangerous than highly arched ones, but it must be borne in mind that the truly dangerous condition of movement of the center of pressure would be represented on the curve sheet by the most


Angles of Inclination
Entering edge of plane
Centre of plane
Rear end of plane
Position of C.P. as % depth of plane
Curve No 9
POSITION of C. P.
on
ARCHED SURFACES
1. Eiffel ; depth of arch, 1/13.5 chord
2. Prandtl ; " " " , 1/10 "
3. " ; " " " , 1/14 "
4. " ; " " " , 1/25 "

nearly horizontal line. This indicates that at angles of from 0 deg. to 5 deg. the 1/10 curve is the most unstable.

THE DISTRIBUTION OF PRESSURE

M. Eiffel also investigated the distribution of pressure over a curved plane set at 10 deg. Some of his results are shown in the diagram on this page, where 3, 2, 1, 0, — 1, and — 10, — 8, — 4, etc., are numerical quantities, indicating the relative value of the pressures, the distribution of which are shown by the contour-like lines on the surface. On line 3, for example, every point is at a pressure, three times as great as that of every point on line 1.



THE DISTRIBUTION OF PRESSURE ON A PLANE SURFACE (EIFFEL)

The dotted lines, —1 on the under surface, indicate a negative pressure at these points; and this leads at once to the conclusion that it is advisable to "round" the ends of the planes, as is done on the Blériot, Wright, etc.

The considerable negative pressure on the upper face at the front suggests possibly that in this region there is a pronounced Bernouilli effect.

[1]Joessel, Memorial du Genie Maritime, 1870.
[2]Kummer, Berlin Akad, Abhandlungen, 1875, 1876.
[3]Langley, "Experiments in Aerodynamics," Chapt. 8.
[4]Rateau, A., Aerophile, v. 17, p. 330, August, 1909.
[5] Prandtl, Mitt. Coettingen Aerodyn. Lab.; Zeit. fur Flug. v. Motorl., 1910.

CHAPTER VII.

THE EFFECT OF DEPTH OF CURVATURE AND ASPECT RATIO UPON THE LIFT AND DRIFT OF CURVED PLANES

There has been much discussion among those actively interested in aviation about the effect that varying the curvature of a plane or changing its aspect ratio has on the lift and drift. The experiments of Prof. Prandtl have done much to settle these questions, however, and their results are so forcibly brought out that many of them may well be considered conclusive.

DEPTH OF CURVATURE

Curve No. 10, page 69, shows the drift variation with angle of incidence, for three surfaces of different curvature, but all of the same size and aspect.

The results show that the drift resistance decreases as the depth of curvature decreases. In other words, under the same conditions, a flatter plane has a much less dynamic resistance than a highly arched one. It is largely for this reason that flatter planes are more suitable to a racing machine. It must be borne in mind, however, that these experiments were conducted on planes of circular curvature, and the conclusions arrived at are only applicable to such planes. Where the section is more like that of a bird's wing, very thick at the front, or where the greatest depth is within a third of the width (distance from front to back of a plane), from the leading edge, the conditions are likely to be quite different, especially at high velocities.

Curve No. 11, page 70, shows that the lift of a plane increases greatly as the curvature is made deeper. That a flatter plane lifts less than a highly arched, however, has long been surmised. The lift of the 1/14 plane appears greater at small angles than any of the others. This may be due to experimental errors.

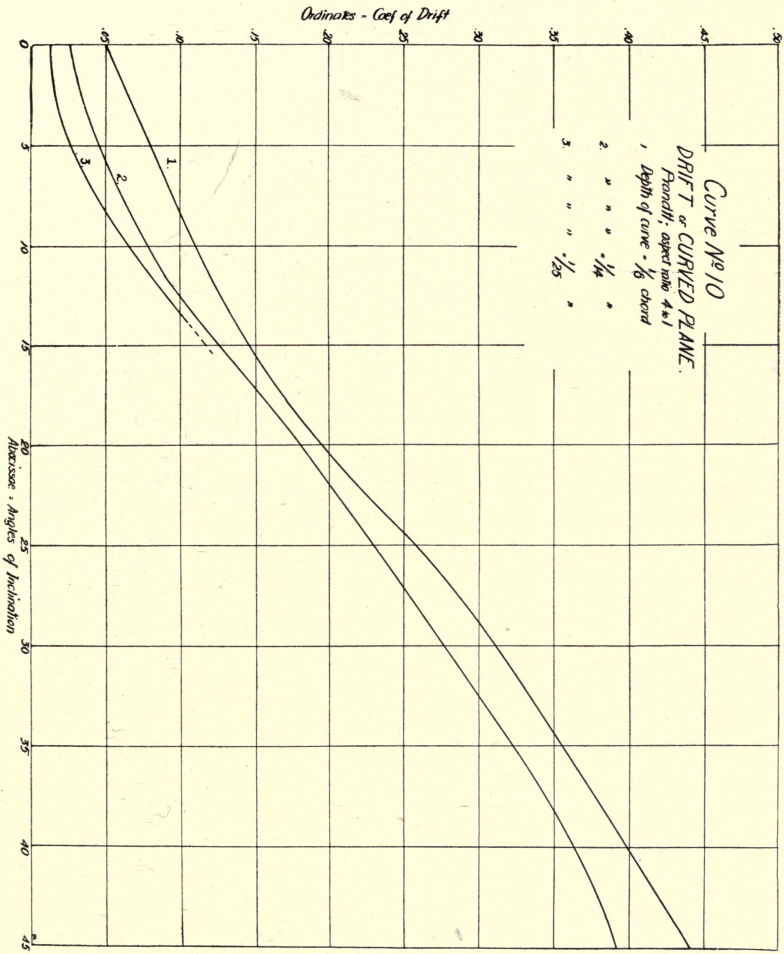
Curve No. 12, page 71, shows the ratio of lift to drift for planes of varying curvature, and it may be concluded from it

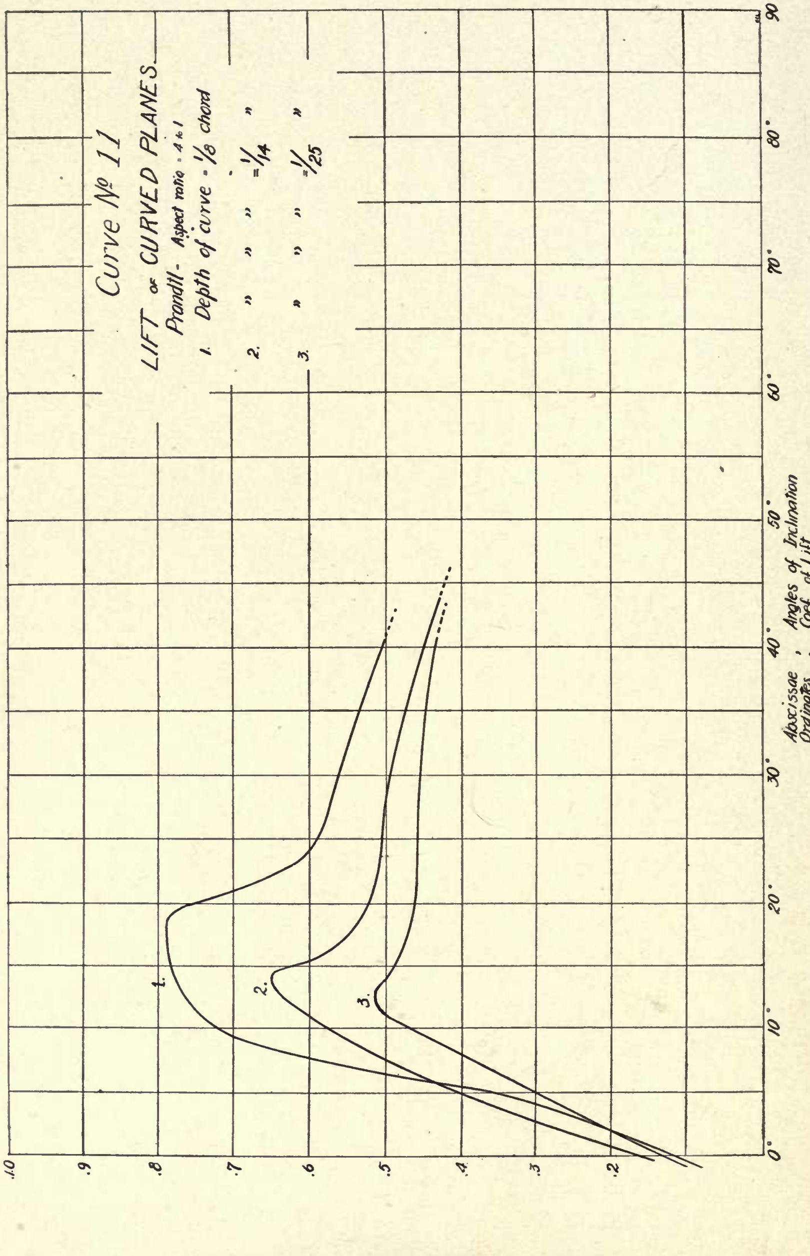
that the ratio of L/D is greatest for the flattest plane, 1/25 depth. The angle at which L/D is greatest varies from the neighborhood of 4 deg. for the 1/25 section, to 9 deg. for the 1/10 section. There is therefore additional reason for using a nearly flat plane for a high-speed machine.

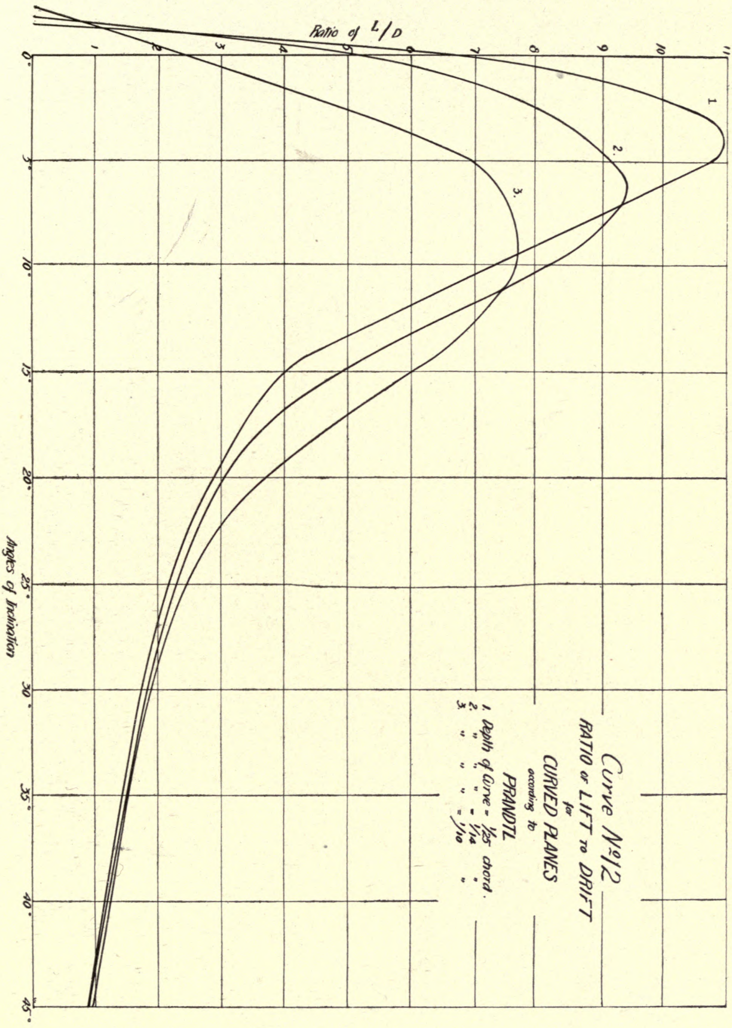
The author concludes from experiments of his own that the ideal section for high speed is a thick leading edge, and a nearly flat under face with a fairly well arched upper face, giving a considerable thickness, about one-third back of the leading edge. This gives all the advantages of a flat plane in reduction of drift, but increases the efficiency by reason of the fact that a well designed upper face will so "influence" and guide the air streams past the surface that few regions of discontinuity will exist. The thickness, however, must not be made too great because of the higher resistance caused thereby. The curved upper face will generate the well marked upward trend of the advancing current of air, a highly advantageous characteristic of curved surfaces that is very pronounced in all stream line photographs; it is even likely that this upward trend has much to do with the increased lift of curved surfaces in that the angle between the air stream and the chord of the surface is much greater than the angle of incidence, i. e., between the chord and the general line of motion of the air stream. Because of this greater angle, the pressure on the plane is increased, and this increased pressure largely turned into lift, the drift remaining about the same, thus giving a much higher efficiency.

Referring to the stream line photograph on page 48, a region of discontinuity is observed at the rear. trailing out from the rear edge, and obviously due to the sudden passage of the air stream past this sharp edge. This action certainly decreases the efficiency by increasing the resistance. It would appear, therefore, that a gentle upward reverse curvature of the rear edge might add to the efficiency.

Not long ago W. R. Turnbull conducted a series of experiments on differently shaped sections of planes,[2] and found that a section of this "reverse curve" type gave excellent lift and a


Curve Nº 10
DRIFT of CURVED PLANE.
Prandtl; aspect ratio 4 x 1
1 Depth of curve - 1/6 chord
2. " " " - 1/14 "
3. " " " - 1/25 "
Ordinates - Coef of Drift
Abscissae : Angles of Inclination
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
0
5
10
15
20
25
30
35
40
45
1.
2.
3.


Curve No 11
LIFT of CURVED PLANES
Prandtl - Aspect ratio = 4 to 1
1. Depth of curve = 1/8 chord
2. " " " = 1/14
3. " " " = 1/25
Abscissae ; Angles of Inclination
Ordinates ; Coef. of Lift
0° 10° 20° 30° 40° 50° 60° 70° 80° 90°
.2 .3 .4 .5 .6 .7 .8 .9 1.0
1. 2. 3.


Ratio of L/D
Angles of Inclination
Curve No. 12
RATIO OF LIFT TO DRIFT
for
CURVED PLANES
according to
PRANDTL
1. Depth of Curve = 1/25 chord.
2. " " " = 1/14 "
3. " " " = 1/10 "

very low drift. Incidentally, he also found that in this kind of a surface, the movement of the center of pressure was very regular, and therefore gave much greater stability. The outer ends of the v. Pischof and Etrich monoplanes (see Part II, Chapter X) are turned up, somewhat in this fashion, and it is found that this disposition, suggested some years ago by Tatin, greatly adds to the stability.

ASPECT RATIO

There is little necessity for dwelling at length upon the advantage of a high aspect ratio, i. e., the ratio of the span of a plane to the depth, chord, or distance parallel to the direction of the air stream. That a broadly spreading plane of small chord gives a much better efficiency than a short span plane with its longest dimension from front to rear, has long been known.

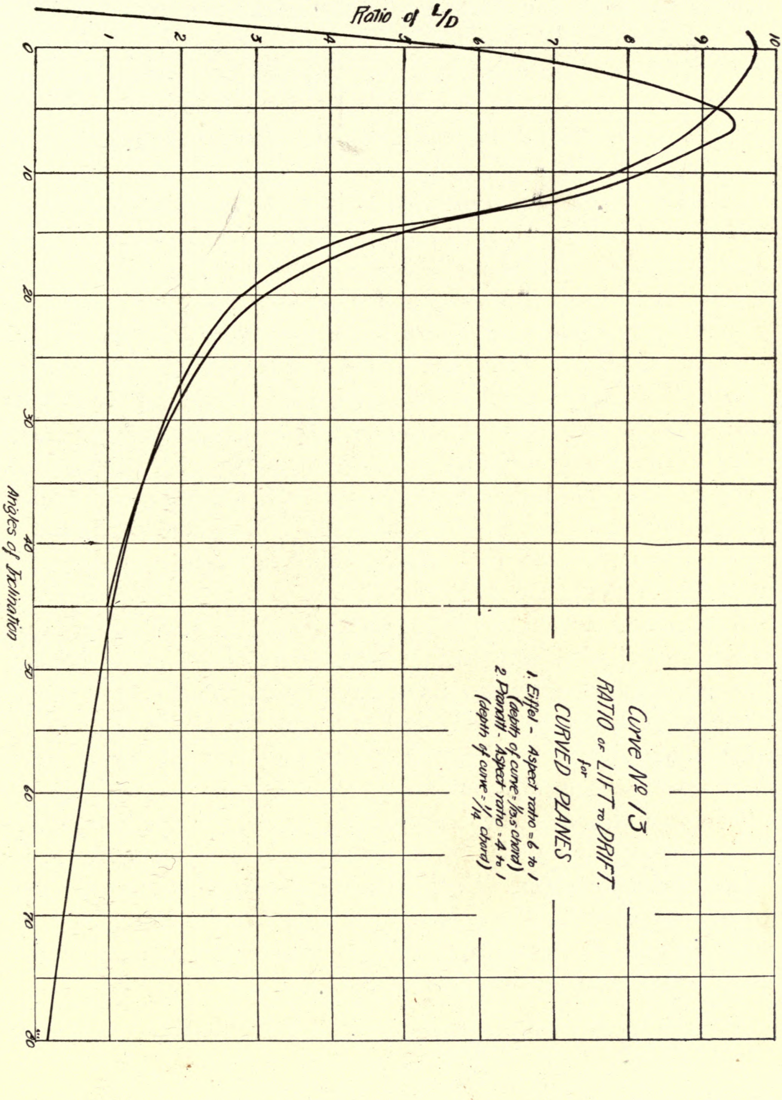
It is interesting, nevertheless, to compare the results of Eiffel and Prandtl on planes of different aspect ratio as is done in curve No. 13, on page 73.

Eiffel's plane measured 900 millimeters in span and 150 millimeters in depth, giving an aspect ratio of 6 to 1. Prandtl's plane measured 80 centimeters in span and 20 centimeters in depth, giving an aspect ratio of 4 to 1. The curvatures of the two planes were similar. Yet the ratio of lift to drift does not show any noticeable difference except at angles below 4 deg. At 0 deg. there is a very great difference, the plane with the high aspect ratio having a much higher efficiency.

In curve No. 14, page 77, are given the results of Prandtl's experiments on planes of the same curvature (3/40) but of different aspects. Here there is a very distinct variation, the ratio of lift to drift decreasing greatly as the aspect ratio is decreased. For the 5.25 to 1 plane, it is nearly 12, and for the 1 to 1 it is 4.9.

The different planes have their maximum values of L/D at about the same region, 4 deg. to 6 deg.

Comparing curves No. 13 and No. 14, it becomes at once evident that Eiffel's results for the 6 to 1, and Prandtl's for the 5.25 to 1, bear little resemblance. Prandtl's curve, although smaller


Ratio of L/D
0
1
2
3
4
5
6
7
8
9
10
Angles of Inclination
0
10
20
30
40
50
60
70
80
Curve No 13
RATIO of LIFT to DRIFT.
for
CURVED PLANES
1. Eiffel - Aspect ratio = 6 to 1
(depth of curve = 1/13.5 chord)
2. Prandtl - Aspect ratio = 4 to 1
(depth of curve = 1/14 chord)

in aspect, having a higher ratio of L/D than Eiffel's. The results are therefore not in good accord, and emphasis should be laid on this fact to show how even at this stage, two of the most prominent experimenters can differ in their results. Excepting in one or two points such as these, however, it must be acknowledged that the results of Prandtl, Eiffel, Rateau, Spratt, Lilienthal, Langley, and others, do bear each other out quite well.

Exactly why a high aspect ratio is so beneficial is not known, but it may possibly arise from two causes. First, there must be a leakage of air around the lateral edges of a plane, and naturally the smaller these edges the less the leakage. A long plane with a small span would permit of a much greater flow of air out past its sides than along under it and out at the rear; while a very broad plane with a small depth would have the air stream largely pass under it and out to the rear, and little leakage past the sides. This at once suggests that a shape of plane (in plan, not in section) could be designed in which all the advantages of a high aspect ratio are preserved without the excessively wide span, a shape something like that of the Paulhan biplane. (See Part II, Chapter XI, page 210).

The second advantageous characteristic of a high aspect ratio is not so well defined. It is a fact observable from the stream line photographs that the air stream passing under an inclined plane is gradually deflected until it leaves the region of the rear edge practically tangential to the surface. But, obviously, if it does leave tangentially or nearly so, there can be little or no lift in this region. The plane, therefore, is not so efficient, the drift of course being slightly decreased for this region (due to the lesser incidence), but the lift being decreased in very much greater proportion. The ratio of this "dead" region to the effective area in front of it would certainly be greater on a plane of low aspect ratio than on one of high aspect ratio.

[1] Prandtl, Mitt. Goettingen Aerodynamischen Laboratorium; Zeit. fur Flug. v. Motorl., 1910.

[2] Turnbull, W. R., "Forms and Stability of Aeroplanes," Sci. Am. Supp., v. 67, p. 68.

CHAPTER VIII.

NUMERICAL EXAMPLE OF THE DESIGN OF AN AEROPLANE

To illustrate numerically the application of the theoretical matter and experimental data contained in the preceding chapters of this volume, the following example is given. Calculations in this kind of work need be made only to 5 or 10 pounds for lift, and 1 or 2 pounds for drift. Any refined calculation to hundredths or even tenths of a pound has no *raison d'etre.*

DESIGN OF A BIPLANE

Weight, speed and angle of incidence assumed: to find the area and dimensions of the planes and rudders and the motive power necessary.

Let W = total weight (including operator) = 1000 pounds. Let the desired speed $V = 45$ miles an hour, and let the angle of incidence be assumed provisionally at 5 deg. We must first choose a type of curvature. This being a rather slow and heavy machine a 1/12 curve would answer well. A convenient aspect ratio such as 5½ to 1 must also be chosen. and depends primarily on the type of structure and materials to be used.

Since the lift must equal the weight W, we have, according to Lilienthal, for a 1/12 curve,

$$L^1 = 1000 = [(\cos 5 \text{ deg.} \times n) + (\sin 5 \text{ deg.} \times t)] \times P_{90}$$

and referring to the Lilienthal table, page 49, and to a table of natural trigonometric functions quite accurate enough to three places for this kind of work, we get cos 5 deg. = 0.996 and sin 5 deg. = 0.087. Then

$$L' = 1000 = [\ (0.996 \times 0.650) + (0.087 \times 0.014)\ ]\ P_{90}$$
$$= 0.648\ P_{90}$$

$$\therefore P_{90} = \frac{1000}{0.648} = 1550 \text{ pounds.}$$

Lilienthal's values for lift, however, especially at 5 deg., are now generally conceded to be too high for reasons explained in Chapter IV.

If we used Eiffel's results (see page 54), the values obtained are:

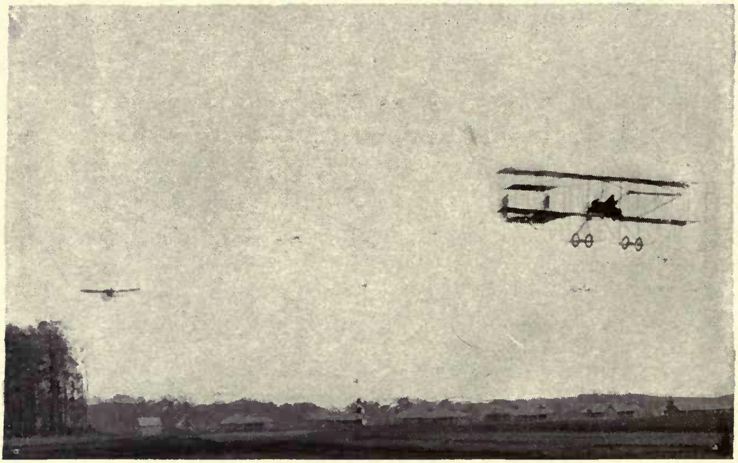
$$L = Ky \times SV^2$$

$$1000 = 0.00224 \times S\ V^2$$

whence
$$L = \frac{0.00224}{0.00314}\ 0.00314\ SV^2$$

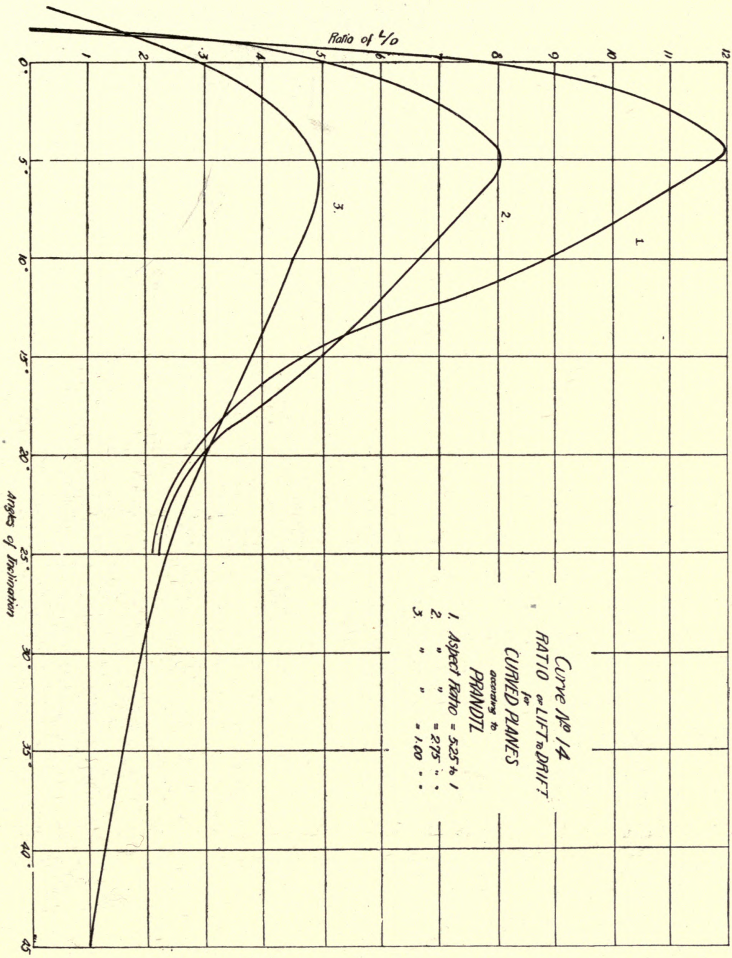
and
$$1000 = 0.71\ P_{90}, \text{ giving}$$

$$P_{90} = \frac{1000}{0.71} = 1410 \text{ pounds.}$$



AT BELMONT PARK. OCT., 1910
A Farman biplane closely followed by a Blériot monoplane.

But in this case, it must be borne in mind that the aspect ratio is 6 to 1 and the curvature 1/13.5, both leading to a high lift, so that the value 0.71 is very likely 10 to 15 per cent too high.


Ratio of L/D
Angles of Inclination
Curve No 14
RATIO of LIFT to DRIFT
for
CURVED PLANES
according to
PRANDTL
1. Aspect Ratio = 5.25 to 1
2. " " = 2.75 " "
3. " " = 1.00 " "

In Curve No. 10 are plotted the values of drift for a plane with a 1/14 depth of curvature. Although the aspect ratio is 4 to 1 for this surface, the effect of an increase of aspect ratio to a higher value would not appreciably alter the drift; it would only increase the lift. In Curve No. 14 are plotted the values of Lift/Drift for a plane having an aspect ratio of 5.25 to 1 and a curvature of very nearly 1/12. For 5 deg., L/D from Curve No. 14 equals about 12, and from Curve No. 10, it is seen that the drift coef. equals .04. Therefore the lift coefficient upon combining equals $12 \times 0.04 = 0.48$.

Then $$L = 1000 = 0.48\, P_{90}$$

and $$P_{90} = \frac{1000}{0.48} = 2080 \text{ pounds.}$$

Since $$P_{90} = KSV^2 = 0.003\ \ S \times 2025$$
$$P_{90} = 6.075\ S \text{ or } S = P_{90}/6.075$$

which gives $S = 256$ square feet by Lilienthal; $S = 232$ square feet by Eiffel and S = 345 square feet by Prandtl.

The values of both Lilienthal and Eiffel are certainly very low, and to be on the safe side, we will use the more reliable results of Prandtl.

We may therefore say that the required area is 350 square feet.

This is the area necessary to give the lift of 1,000 pounds at 5 deg. and at 45 miles an hour.

The aspect ratio is to be in the neighborhood of 5½ to 1.

It has already been said that "rounding" the ends of planes is a very good practice. To do this we must take off about 10 square feet on each end of the otherwise rectangular planes. This means that our rectangular dimensions must give 40 square feet greater area, or 390 square feet. Each plane then should have the superficial dimensions of a rectangle 195 square feet in area.

The conditions are entirely satisfied by a biplane, the surfaces of which are rounded at the ends, 32 feet 6 inches in spread (maximum width side to side), and 6 feet 0 inches in chord (maximum distance front to back), giving an aspect ratio of 5.42 to 1.

This is a provisional set of values for the surfaces. If the aspect ratio or depth of curvature is to be changed, the corresponding changes in the constants will give a different P_{90} and a different surface, the choice of values, as in all kinds of en-

A Glimpse of Blériot Shortly After His Start on His Historical Crossing of the English Channel, July 25th, 1909

gineering practice, depending in great measure upon the experience, judgment and technical training of the designer.

P_{90} and the dimensions of the surface being known, the drift can now be calculated.

By Lilienthal, (see Table p. 49).

$$D = [\ (n \sin 5 \text{ deg.}) - (t \cos 5 \text{ deg.})\ ] \times P_{90}$$
$$= [\ (0.650 \times 0.087) - (0.014 \times 0.996)\ ] \times 0.003 \times S \times V^2$$
$$= 0.042 \times 0.003 \times 350 \times 2025$$
$$= 90 \text{ pounds.}$$

Lilienthal's values for drift are generally thought to be quite good.

Using Eiffel's table (see p. 54) $Kx = 0.00025$, and

$$D = 0.00025\ SV^2$$
$$= 0.00025 \times 350 \times 2025$$
$$= 177 \text{ pounds,}$$

a value that is perhaps a little excessive.

By Prandtl's results (see p. 69)

$$D = 0.04 \times KSV^2$$
$$= 0.04 \times 0.003 \times 350 \times 2025$$
$$= 85 \text{ pounds}$$

a value that is low.

Lilienthal's value of the drift is quite reasonable; allowing a large enough factor of safety, we can call the drift 150 pounds.

This 150 pounds is the drift or aerodynamic resistance. To get the necessary thrust of the propeller, we must add to it the head resistance of the body and framing H and the frictional resistance F. Then, if we let R = the total resistance to motion, obviously

$$R = D + H + F.$$
$$= D + K\ S\ V^2 + 2fS$$

To get the head resistance, the cross section of the machine must be reduced to an equivalent flat surface. It is unnecessary to go into the detail of this somewhat laborious computation, but it consists in estimating with a reasonable degree of accuracy:

1. The combined cross-section of wires, struts and framing, all projected on a vertical plane, perpendicular to the line of flight. The simplest way of obtaining this is to determine the cross-section per inch or per foot of the wires allowing 1/16 inch to ⅛ inch for vibration, and multiplying by the number of inches or feet of wire or cable. The same is done for the frame members and the cross spars.

2. The projected area of operator motor tanks, seat, etc.

All these are added together, and if we let this area be A, then

$$H = K\ A\ V^2$$
$$= 0.003 \times A \times 2025$$

In a machine of this size A is about 3 to 4 square feet at the most.

Then $H = 0.003 \times 4 \times 2025$
$= 24.3$ pounds.

The frictional coefficient f is obtained by interpolation from the Table on p. 58, for $V = 45$ and a 6-foot plane.

$$f = 0.0162$$

Then the frictional resistance

$$F = 2 \times 0.0162 \times 390$$
$$= 12.6 \text{ pounds}$$

The resistance of the main biplane cell alone is then:

$$R = 150 + 25 + 13$$
$$= 188 \text{ pounds.}$$

But we have not yet considered the rudders or keels, and their resistance is quite large. Their size in general is dependent upon their distance from the centers of gravity and pressure. If they are very far to the rear as in the Antoinette, then their size need be much less than if they were placed near the center of pressure. Their shape is largely a matter of personal taste. In any case, however, the governing principle in their design, is that they should never be so small, that in order to correct a very bad cant of the machine, they must be inclined at an angle as high as 25 deg. to 30 deg. The pressures at such angles especially on curved surfaces are unreliable, and likely to give only a drag, instead of a righting force.

RUDDER DESIGN

A very simple and efficient method of elevation rudder design is to determine approximately, as we can do from Prof. Prandtl's results, what the maximum movement of the center of pressure is from the normal position that it is supposed to occupy at 5 deg. ~~and over, which the~~ center of gravity is located.

In the diagram on this page, let AB = the main plane, C = the normal position of the center of pressure (and also the center of gravity), and CC^1 = the maximum backward movement of the center of pressure.

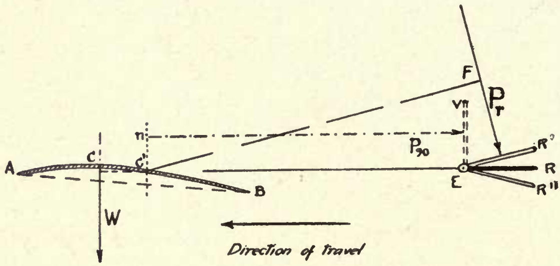
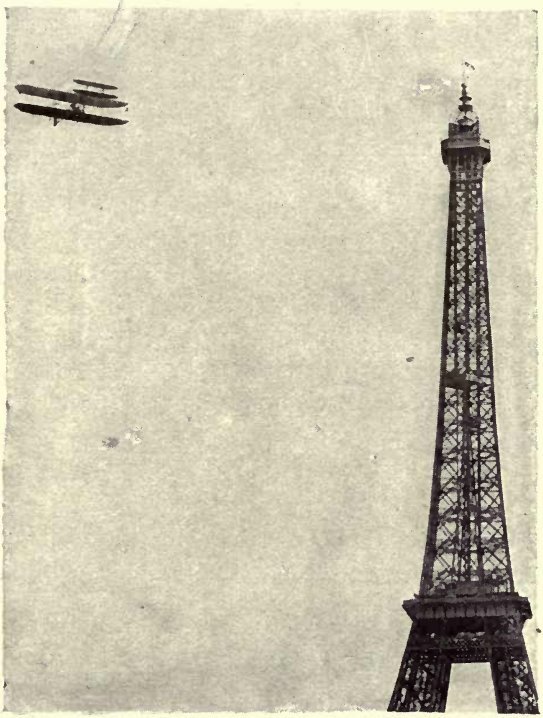


DIAGRAM SHOWING THE FORCES ON AN AEROPLANE SURFACE *AB* AND REAR ELEVATION RUDDER *ER* WHEN THE CENTER OF PRESSURE MOVES FROM *C* TO C^1

Let ER be the normal position of the elevation rudder (placed at the rear as on the Wright, etc.), and ER' ER'', its maximum movement for ascent and descent respectively. The worst movement of the center of pressure is the backward one at low angles. Assuming that C' represents the position for 0 deg., an inclination that no operator is likely to permit in ordinary flight, although he may greatly exceed it if he desires to gain speed by a sudden dive.

Since the center of gravity remains at C, it being assumed that the elevator is normally non-lifting, and that no lifting keels are provided, the weight of the entire machine will act through C, in the direction indicated. C', however, is now the center of support, so that we will have a moment about C', equal to $W \times$ the vertical distance between the action line of W and C', tending to rotate the system in a counter clockwise direction, i. e., the machine will tend to plunge. Incidentally the more sudden the movement of the center of pressure from C to C', the more dangerous will be this plunge, and there is great possibility that a sudden movement of this kind due to a quick change in the direction of a gusty head wind, has caused several of the recent accidents.

To correct this tendency to dive, we must make the elevation rudder of such size that when turned up to position ER', the pressure on it shown as $P\gamma \times$ the vertical distance FC', will give a moment tending to rotate the system clockwise, and not only equal to, but a little greater than the moment of W due to its lever arm about C'. Obviously the farther back we place ER, the greater is



COUNT DE LAMBERT CIRCLING THE EIFFEL TOWER IN HIS FLIGHT OVER PARIS ON OCT. 19TH, 1909. HE USED A WRIGHT BIPLANE

its lever arm, and consequently for the same desired righting moment, the less need be the value of $P\gamma$ (i. e., the smaller the surface necessary). The reason why ER should never be turned at

too great an angle, is easily shown. If it is turned to the position EV, then there is acting on it the normal force P_{90}. The action line of this force is $m\ n$, and its value not very much greater than P_γ. But its lever arm about C' is nC', and gives so small a clockwise moment that the rudder is practically ineffective.

This same analytical method is applicable to the determination of the conditions for the correction of the maximum forward movement of the center of pressure, causing the aeroplane to tip up and necessitating a movement of the rudder to ER''. It may also in a measure be extended to determine the size of direction rudders and of lifting keels.

Returning to our example, and referring to curve No. 9, p. 65, it is seen that the position of the center of pressure for a surface of this kind is about 44 per cent of the chord of the plane at 5 deg. from the front edge. This, then, is to be the position of the center of gravity. At 0 deg. it is seen that the center of pressure has moved back to a point 70 per cent of the chord from the front edge. Since the chord is 6 feet, the center of gravity is to be $0.44 \times 6 = 2$ feet 8 inches from the front edge, and of course at the center of the machine transversely. The movement of the center of pressure is to a point 0.70×6 or about 4 feet 2 inches from the front edge of the plane. The lever arm of the force W (see diagram p. 82) is then 1 foot 6 inches.

The weight is 1,000 pounds, therefore the counter clockwise moment tending to cause the machine to plunge is:

$$\begin{aligned} M &= 1000 \times 1.5 \\ &= 1500 \text{ foot-pounds.} \end{aligned}$$

To determine the size of rudder necessary, let us assume the type of structure we use, the strength of the material, and the weight we are limited to, permits of carrying the rudder framework far enough to the rear to make the distance between the center of ER and C' about 30 feet.

The maximum inclination of ER' above ER, is chosen at 15 deg. a reasonable limit.

Then the lever arm $C'F$ is approximately $C'F = 30$ feet $\times$ cos 15 deg.

$$= 30 \times 0.966$$
$$= 28.8 \text{ feet.}$$

The moment desired is to be in excess of 1,500 foot-pounds, and is taken at 1,600 foot-pounds.

$$M' = 1600 = 28.8 \times P_\gamma$$

Whence

$$P_\gamma = 1600/28.8 = 56 \text{ pounds.}$$

Assuming that this rudder is a flat plane, curve No. 2 p. 39 shows that when $\alpha = 15$ deg., $P_\alpha/P_{90} = 0.46$.

Then,

$P_{90} = P_\alpha/0.46 = 56/0.46 = 122$ pounds.

The size of surface can now be obtained.

Since $P_{90} = KSV^2$

$$S = P_{90}/KV^2 = 122/0.003 \times 2025$$
$$= 122/6.075 = 20 \text{ square feet.}$$

A very good shape of rudder therefore is a plane 10 feet spread and 2.5 feet depth, rounded at the corners.

If the aeroplane is to be used for speed only, this size could be slightly reduced. If it is to be used for fancy volplanes and spirals, it would certainly be wise to increase its size.

The dynamic resistance of this rudder is,

$$D_\gamma = P_\gamma \sin 15 \text{ deg.}$$
$$= 56 \times 0.259 = 14.5 \text{ pounds.}$$

MOTIVE POWER, ETC.

The extra resistance of the direction rudder, etc., may be taken roughly at 15 pounds. Then the total resistance is equal to:

$$R^1 = D + H + F + D_\gamma + 15$$
$$= (150) + (25) + (13) + (14.5) + (15)$$
$$= 217.5 \text{ pounds.}$$

This is the actual active thrust of the propeller, T, necessary to keep the machine in flight, if all these resistances acted at once, a condition that is possible.

The power required is the force $\times$ the distance moved per unit time.

$$\text{Power} = T \times V = 220\ V$$

expressed in foot-pounds per minute, when T the thrust is given in pounds, and V in feet per minute.

$$V = 45 \text{ miles per hour}$$
$$= 3960 \text{ feet per minute}$$

$$\therefore \text{Power} = 220 \times 3960 = 871{,}200 \frac{\text{ft. lbs.}}{\text{min.}}$$

$$1 \text{ Horse-power} = 33{,}000 \text{ ft. lbs./min.}$$

$$\therefore \text{Horse-power} = \frac{871{,}200}{33{,}000} = 26.4 \text{ horse-power.}$$

This is all the power necessary in the motor if the generation and transmission of the power were perfect. This is never the case. The propeller delivers roughly only 75 to 80 per cent of the power put into it. The motor itself and the transmission may cause another 5 per cent loss. Therefore, to obtain the power of the motor necessary, at its ordinary commercial rating, we may consider the system 70 per cent efficient.

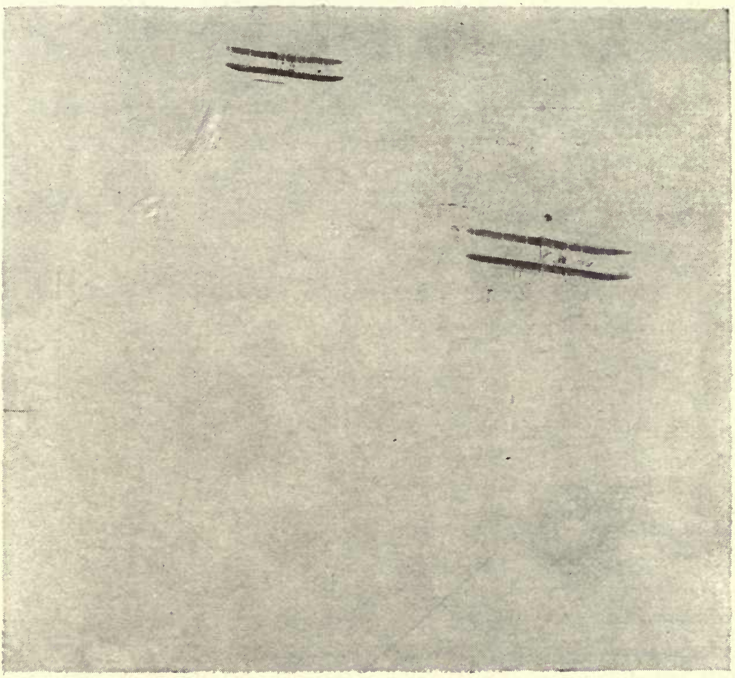
This gives the horse-power of motor

$$= \frac{26.4}{0.7} = 38 \text{ horse-power.}$$

Therefore, for this machine a 40 horse-power motor will be amply sufficient. However, if great quickness and ease of starting is desired, or if the machine is to be flown at a high altitude, more power will be needed.

In order to design the propeller, we may assume the r. p. m. of the motor at 800. In propeller design, if it may be called such, practical experiment is infinitely more successful than volumes of theoretical calculations. The propeller industry is well advanced, and many of the propeller manufacturing concerns have finally been enabled by experiment to construct propellers suitable to different types of machines and speeds with great success. It is hardly necessary to go into the shape, pitch, or form of the blades here, as these points are largely matters of personal experience, and individual conditions. We may, however, obtain a rough idea

of the diameter necessary by applying the Drzewiecki method, one of several that works out reasonably well, and given in full in his "Des Helices Aeriennes" (1909).



"THE HEAVENLY TWINS"

Johnstone and Hoxsey as they were popularly called at Belmont Park, Oct. 1910, climbing for altitude.

The two useful equations of this elaborate theory are:

$$m = \frac{V}{2\pi n}$$

and $d = m \times 10$

Where m is a constant called the "modulus," $V =$ the velocity in meters per second, $n =$ the revolutions per second, and $d =$ the

diameter of the propeller in meters. Converting the values we already have into their proper units, we get:

$$V = \frac{66}{3.28} = 20 \text{ meters per second.}$$

$$n = 13 \text{ r. p. s.}$$

Then $$M = \frac{20}{2\pi \times 13}$$

$$= \frac{20}{6.28 \times 13} = 0.245$$

and

$$d = 0.245 \times 10 = 2.45 \text{ meters}$$

$$= 2.45 \times 3.28 = 8 \text{ feet.}$$

SUMMARY

In this manner we arrive at the design of a biplane with the following characteristics:

Supporting Area = 350 square feet.

Spread = 32 feet 6 inches.

Chord = 6 feet.

Angle of incidence = 5 deg.

Depth of curvature = 1/12 chord.

Weight = 1000 pounds.

Elevation rudder = 10 feet by 2 feet 6 inches, placed 30 feet to rear, and non-lifting.

Motor = 40 horse-power 800 r. p. m.

Propeller = 8 feet in diameter.

Aspect ratio = 5.42 to 1.

Speed = 45 miles per hour.

Pounds carried per horse-power = 25.

Pounds carried per square foot of surface = 2.86.

The details of the controlling devices, transverse control, shape and position of rudders, propeller, motor, operator, etc., and the type of mounting are matters of personal choice. In Part II, the different dispositions used on the various successful machines

are given in detail. In Part III, their advantages and disadvantages are discussed.

This example, however, indicates with what a degree of success an aeroplane may be designed, by the use of the most elementary mathematics combined with experimental values of the pressures on aeroplane surfaces.

In a monoplane, the process of design would be similar in every respect. The monoplane has, in general, less head resistance than the biplane, a modification which means that for the same power, a greater speed can be obtained and therefore a smaller surface is needed for support.

PART II.

DETAILED DESCRIPTIONS OF THE NOTABLE AEROPLANES

CHAPTER IX.

INTRODUCTION

The rapid progress that has been made in the practical application of the principles of Aerodynamics is almost unparalleled in the history of science. Within a year, the number of men making extended flights has increased so greatly, that we are warranted in classing artificial flight with other established means of locomotion.

The development of the aeroplane has been accompanied by the improvement of the dirigible balloon or aeronat, as technically termed; and the advance of both can undoubtedly be traced to the combination of high power and low weight offered by the gasoline engine.

In the case of aeronats, however, as early as 1884 the non-rigid type that we have to-day had been practically developed in the dirigible "La France," built by Col. Renard; and although much progress has been made, it has been more in the line of actual construction than in the development of any new principles.

The successful aeroplanes which have been evolved, although similar in their fundamental characteristics, have begun to vary from each other in many important details of size, arrangement and efficiency of parts. It seems, therefore, that we are at a stage where an examination of these various types for the purpose of comparison, and a discussion of their distinguishing features, merits, and demerits would prove of value.

The order in which the types are taken up is merely a convenient alphabetical one adopted here, and is not based on any quality of the machines. The biplanes and the monoplanes are separated, as they represent two distinct systems.

Many other systems of heavier-than-air machines have been constructed, including several triplanes and some extremely inter-

esting helicopters and ornithopters, but as yet none of these has demonstrated successful flying qualities, except the Roe triplane.

For the purpose of more clearly showing the variations in size of the different types, detailed and dimensioned plans and elevations of each machine are given. Most of these are drawn to the same scale, thus establishing a direct graphic comparison of the types.

It is to be borne in mind that inasmuch as aviators are constantly changing and rechanging the dimensions of their machines, without recording such alterations, many of the dimensions given here are necessarily approximate. In all cases, however, the most recent and accurate data as furnished by the large number of references consulted, as well as by close personal inspection, have been made use of.

DEFINITIONS

In the science of Aviation it has been necessary to use a number of new terms.

By "supporting plane" is meant the main lifting surface as distinguished from all auxiliary or stabilizing surfaces.

The term "direction rudder" refers to the movable vertical surface used for steering to right or left, while the "elevation rudder" is that horizontal surface which is used for steering up or down.

"Transverse control" is the device used for the preservation of lateral balance in wind gusts, and for artificial inclination when making turns.

"Keels" are fixed surfaces exerting neither lifting effect nor rudder action.

"Spread" is the maximum horizontal dimension perpendicular to the line of flight, while "depth" is the dimension of the plane parallel to the line of flight.

By "aspect ratio," is meant the ratio of spread to depth, a means of defining the shape of surface.

"Fuselage" is a long narrow girder-like frame, often containing the motor seat, etc. It could be called the "backbone" or "spine" of a monoplane.

"Empennage" is a keel or fin, similar in character to the tail of an arrow.

"Nacelle," is a boat-like enclosed body, containing the seat, motor, etc., but it is distinguished from "fuselage" in that it plays no part in holding the rigidity of the structure.

A "tractor," screw pulls a machine (as on the Antoinette), while a "propeller" screw pushes a machine (as on the Wright biplane). The term "propeller," however, generally refers to both kinds of screws.

A plane is said to be at a "dihedral angle," when both sides are inclined upwards (positive) or downwards (negative) from the center.

"Angle of Incidence" is the angle between the chord of the plane and the relative direction of the air stream, (see Part I). Often the term "incidence," alone, is used in reference to this angle.

"Fusiform," "stream-line form," "spindle-shaped," are terms descriptive of the torpedo-like shape of a body that gives small resistance.

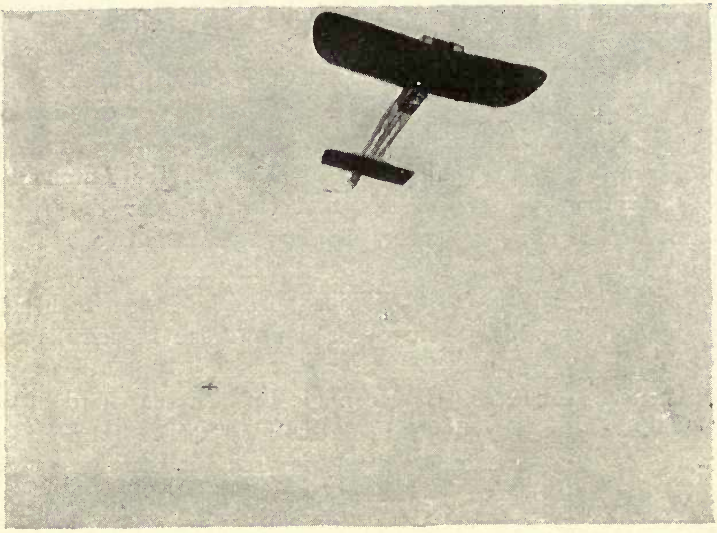
The "Mounting," or "chassis," is the apparatus or framework upon which the aeroplane rests, starts, and alights.

"Camber" is the rise in the arching of a curved plane (see p. 46).

"Chord" is identical with "depth."

"Ailerons," or "wing-tips" are small auxiliary planes used to preserve the side-to-side balance of an aeroplane.

"Loading" is a factor indicating the load in pounds that is carried per square foot of supporting surface.



Monoplanes at Rest and in Flight

CHAPTER X.

IMPORTANT TYPES OF MONOPLANES

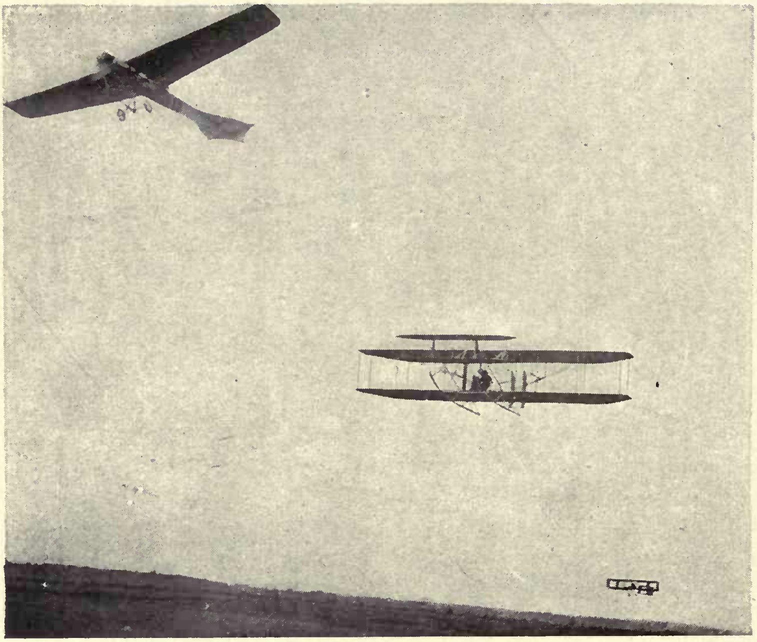
Monoplanes exhibit almost as great a variety of forms as biplanes, and by actual statistics it appears that the number of monoplanes flying, is far greater than the number of biplanes, especially in France. This is very likely due to their greater cheapness and simplicity of structure and the higher speed generally attainable.

As in biplanes, there are many prominent types that bear such close resemblance to types described here, that they need not be separately considered. The Albatross monoplane is a duplicate of the Antoinette with the exception that it is fitted with a Gnome motor. The Deperdussin and Regy recall the Hanriot, while the Minima and Montgolfier are similar in size and aspect to the Santos-Dumont. The Humber, Avis and Morane-Saulnier, all more or less resemble the Blériot, and the Vollmoeller is very much like the Tellier.

The eighteen types of monoplanes described in the following paragraphs are:

1. Antoinette
2. Blériot XI.
3. Blériot XI. 2bis
4. Blériot XII.
5. Blériot "Aero-bus"
6. Dorner
7. Etrich
8. Grade
9. Hanriot
10. Nieuport
11. Pfitzner
12. Pischof
13. R. E. P. (1909)

14. R. E. P. (1911)
15. Santos-Dumont
16. Sommer
17. Tellier
18. Valkyrie



THE ANTOINETTE MONOPLANE PASSING A WRIGHT AND A VOISIN

The propeller may be seen whirling at the front. The bird-like appearance is striking.

1. THE ANTOINETTE MONOPLANE

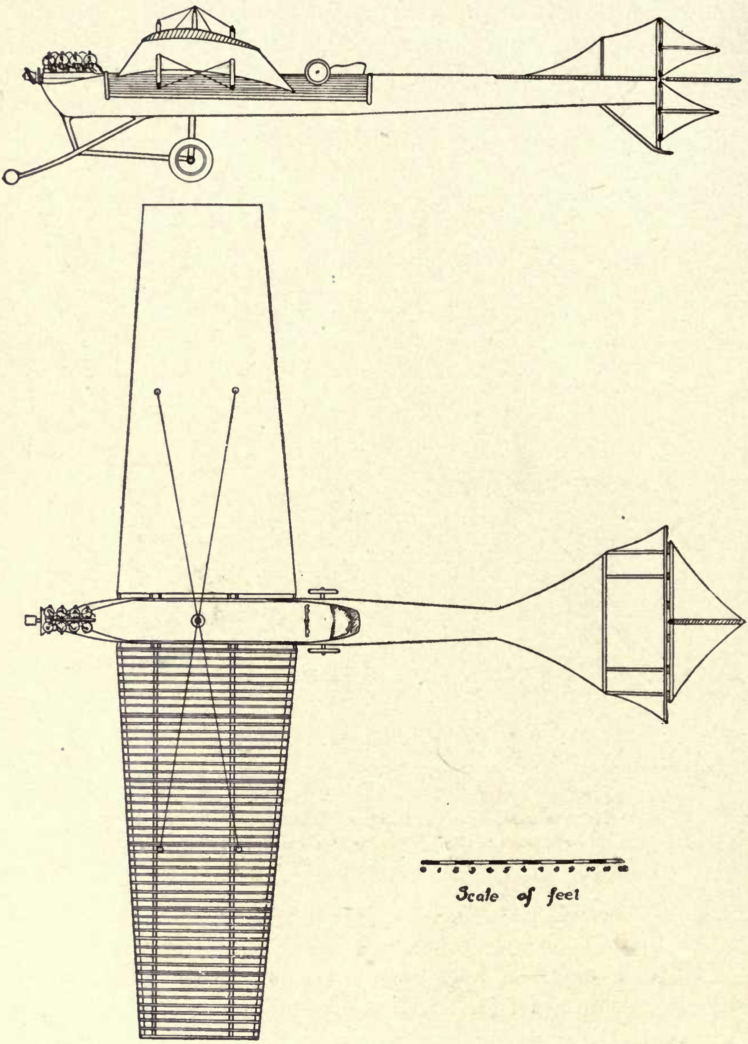
M. Levavasseur, designer of the Antoinette motor boats, is credited with the design of this type. After building some experimental machines, notably the Gastambide-Mengin monoplane,

the "Antoinette IV." was built for M. Latham. This machine was controlled transversely by means of wing tips, while at present the warpable surface control is used. The Antoinette is very large and remarkably well built from an engineering standpoint, and has been operated very successfully by M. Latham in exceptionally high winds. Messrs. Kuller, de Mumm, Thomas, and Labouchère, have also flown monoplanes of this type, and several have been purchased by the French army. The Antoinette, because of its un-

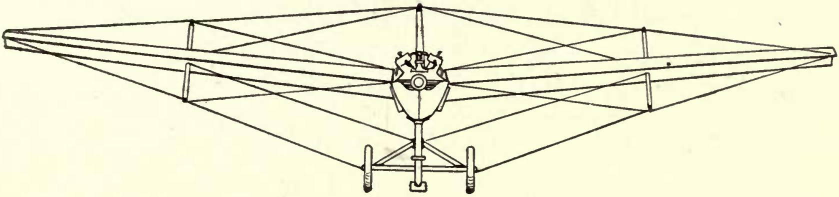
LATHAM'S ANTOINETTE SOARING ABOVE THE TREES IN THE INTERNATIONAL CUP RACE AT BELMONT PARK, OCT. 29TH, 1910

usual gracefulness always attracts a great deal of attention and admiration.

The Frame.—A long narrow frame of cedar, aluminum and ash carries at its front portion the main plane, at the extreme front end the propeller, and at the rear the rudders. At the bow the frame resembles the hull of a motor boat, while at the rear it is built in the form of a triangular latticed girder.



SIDE ELEVATION AND PLAN OF THE ANTOINETTE



FRONT ELEVATION OF THE ANTOINETTE

M. HUBERT LATHAM SEATED ON THE ANTOINETTE MONOPLANE

The left hand wheel seen here governs the warping of the planes. The wires leading from the drum are distinctly visible.

The Supporting Plane.—The carrying plane consists of a single surface divided into two halves of trapezoidal shape set at a slight dihedral angle and constructed of rigid trussing nearly 1 foot thick at the center, covered over and under with a smooth, finely pumiced silk. The plane is braced also from a central mast.

The spread is 46 feet, the average depth 8.2 feet, and the surface area 370 square feet.

The Direction Rudder.—The direction rudder consists of two

A 100-H. P. ANTOINETTE

Note the boat-like bow, the radiator along the sides of the body, and the searchlight.

vertical triangular surfaces at the rear, of 10 square feet area. They are moved jointly by means of wire cables running from a lever worked by the aviator's feet. When this pedal, which moves in a horizontal plane, is turned to the left the aeroplane will turn to the right, although in some cases the opposite disposition is used.

The Elevation Rudder.—The elevation rudder consists of a single triangular horizontal surface placed at the extreme rear, and 20 square feet in area. It is governed by cables leading from a wheel

placed at the aviator's right hand. To ascend, the wheel is turned up. This causes the inclination of the elevation rudder with regard to the line of flight, to be decreased and the machine, therefore, rises.

Transverse Control.—The transverse equilibrium is corrected by warping of the outer ends of the main plane very much as in the Wright machine. But the front ends are movable and the rear ends rigid throughout in the Antoinette, while the opposite is the case in the Wright biplane.

The wheel at the aviator's left hand, through cables and a sprocket gear, placed at the lower end of the central mast, controls the warping. For correcting a dip downward on the right the right end of the wing is turned up, and at the same time the left end is turned down, thus restoring balance.

The controlling apparatus is described fully in Chapter XIII.

Keels.—At the rear, leading up to the rudders, are tapered keels, both horizontal and vertical, that add greatly to the bird-like appearance of the aeroplane.

Propulsion.—A 50 horse-power, 8-cylinder Antoinette motor, placed at the bow, drives direct a two-bladed Normale, wooden, propeller of 7.25 feet diameter and 4.3 feet pitch at 1,100 revolutions per minute.

The Seat for the aviator is placed in the frame back of the main plane. A seat for a passenger is provided in front of and a little below the aviator's seat.

The Mounting is essentially on a large pair of wheels fitted to a pneumatic spring, and placed at the central mast. In addition a single skid to protect the propeller when landing is placed in front, and another is attached in the rear.

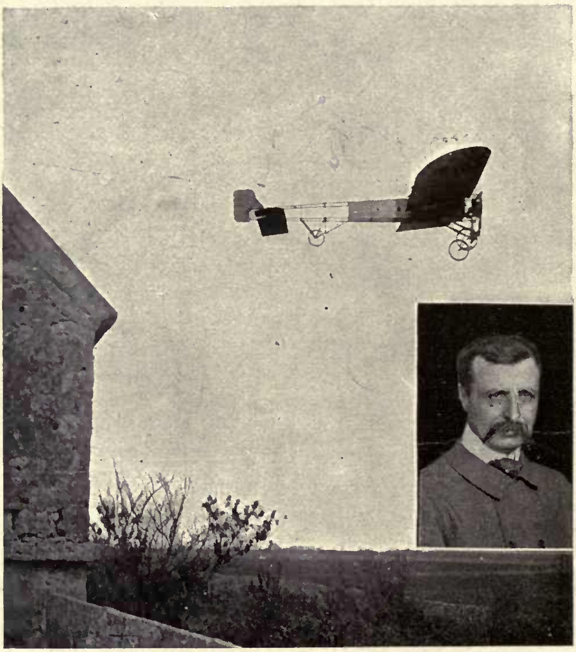
Weight, Speed, Loading and Aspect Ratio.—

The total weight is from 1,040 to 1,120 pounds; the speed is 52 miles per hour; 22.4 pounds are lifted per horse-power, and 3.03 pounds per square foot of supporting surface. The aspect ratio is 5.6 to 1.

Recent Alterations.—The Antoinette has been slightly altered. The spread is now 49.3 feet, the area 405 square feet, and the total

weight from 1,200 to 1,350 pounds. Twenty-seven pounds are lifted per horse-power and 3.33 pounds per square foot of surface. The aspect ratio is 6 to 1. A new 100 horse-power type is also being used for racing.

References.—Aerophile, v. 17, pp. 7, 488; Flight, v. 1, pp. 662, 681; Aeronautics, v. 4, p. 63; Sci. American, v. 100, p. 352; Rev. de l'Av., v. 4, p. 27; La Nature, v. 37, pp. 49, 329; Zeit. für Luftschiff, v. 13, p. 890; Encyl. d'Av., v. 1, p. 1; La Vie Auto., v. 9, p. 729; Flug Motor Tech., No. 22, p. 10; Boll. Soc. Aer. Ital., v. 6, p. 288; Zeit. Ver. Deut. Ing., v. 53, p. 1759; Genie Civil, v. 55, p. 340.



THE BLERIOT XI IN FLIGHT

M. Louis Blériot, its designer and pilot, the real "father" of the monoplane.

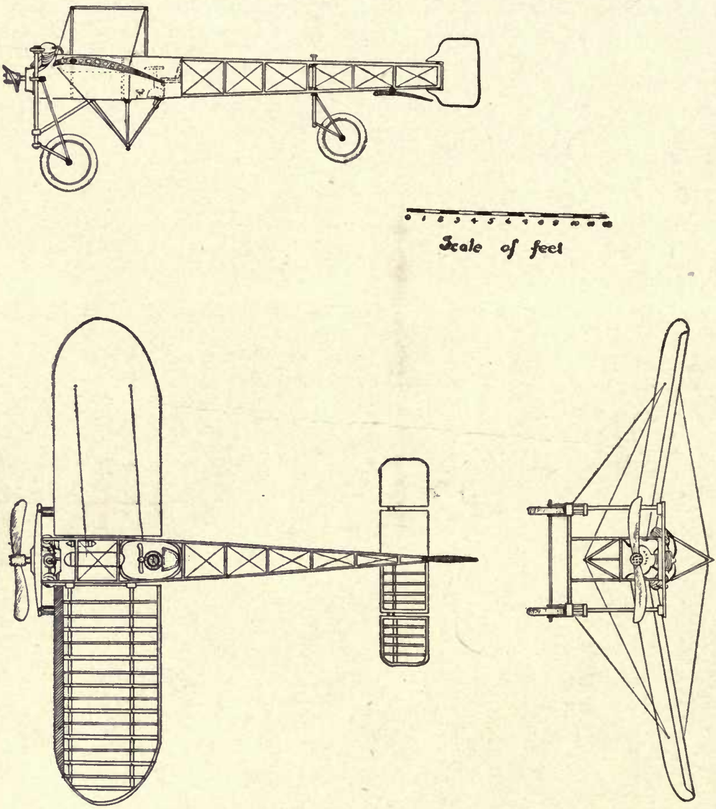
2. THE BLERIOT XI. MONOPLANE

In 1906 M. Louis Blériot constructed and operated the first successful monoplane in the world. He subsequently built type after type, and finally in 1908 succeeded in making several brilliant and extended flights in his large monoplane "No. 8 Bis." Since then he has become world-famous by his flight of July 25th.

CHAVEZ CLIMBING OUT OF HIS BLERIOT XI BIS.

This gives a close view of the central fuselage. Just back of and below Chavez may be seen the seat, control column and a barograph. Part of the planes and one blade of the propeller are also visible. Note the rocker arm for warping and wires leading to the *cloche,* below the fuselage.

1909, when he crossed the English Channel, starting from Calais, and landing near Dover. This flight was accomplished in the No. XI. type monoplane, a small one-passenger machine, which is very simple, and has become extremely popular. Among the noted avi-



THE BLERIOT XI (CROSS CHANNEL TYPE) PLAN AND ELEVATIONS

ators who have flown this aeroplane type are also Delagrange, Le Blon, Aubrun, Morane, Leblanc, de Lesseps, Balsan, and Guyot. Over 300 of these machines have been manufactured and sold by M. Blériot since September, 1909.

The Frame.—The frame consists essentially of a long central body upon which the planes and rudders are attached. This central framework is very lightly but very strongly built of wood, and is cross-braced with wires throughout.

The Supporting Plane.—The main plane is situated near the front, and divided into two halves, each mounted on either side of the central frame by socket joints. The halves of the plane are easily detachable here, and when not in use are dismounted and placed in a vertical position along the frame, thus occupying little room.

The surfaces consist of ribs covered both above and below by Continental rubber fabric. Their curvature is more pronounced than in most other types, and a sharp front edge is obtained by the use of aluminum sheeting. The two halves are at a slight dihedral angle.

The dimensions of the plane are spread 28.2 feet, depth 6.5 feet, and surface area 151 square feet.

The plane is braced above and below by wires from the central frame.

Direction Rudder.—The direction rudder consists of a small surface 4.5 square feet in area placed at the extreme rear. Wire cables leading to a foot lever controlled by the aviator govern the movement of this rudder. For turning to the right, for example, the aviator turns this lever by his feet to the right or left, depending on the disposition installed.

The controlling apparatus is described fully in Chapter XIII.

Elevation Rudder.—The elevation rudder is divided into two halves, one mounted at each extremity of a fixed horizontal keel. The rudder is 16 square feet in area. It is operated by the front and back motion of a "bell crank" or *cloche,* as it is called. This latter device is a universally pivoted lever, in front of the aviator, and in a normal position is vertical. At the lower extremity is attached a bell-shaped piece of metal, affording a means of attachment for the wires, and at the same time covering them to avoid their entanglement in the aviator's feet, etc. To ascend the aviator pulls this lever toward him, and to descend he pushes it away.

Transverse Control.—The lateral equilibrium is controlled by means of the warping of the main plane. The structure of this plane enables it to be warped, as in the Wright machine, but in this case about the base of each half, which is rigidly attached to the frame by the socket joints. The two halves are warped inversely by the side-to-side motion of the *cloche.* If the machine should tip up on the right, then the *cloche* is moved to the right. This increases the incidence of the lowered side and at the same

MOISANT ON HIS BLÉRIOT XI BIS RETURNING FROM HIS FAMOUS STATUE OF LIBERTY FLIGHT, BELMONT PARK, OCT. 30TH, 1910

time decreases that on the raised side, thus righting the machine. The combination of this side-to-side motion of the bell-crank, with the movement of the foot lever controlling the direction rudder, is used in turning.

Keels.—To preserve the longitudinal stability, a single fixed horizontal keel is placed at the rear. Its area is 17 square feet.

Propulsion.—At the front of the central frame is placed the motor, originally a 3-cylinder Anzani, developing 23 horse-power. This motor drove direct at 1,350 r.p.m. a Chauviere wooden propeller, two-bladed, 6.87 feet in diameter and 2.7 feet pitch. Several

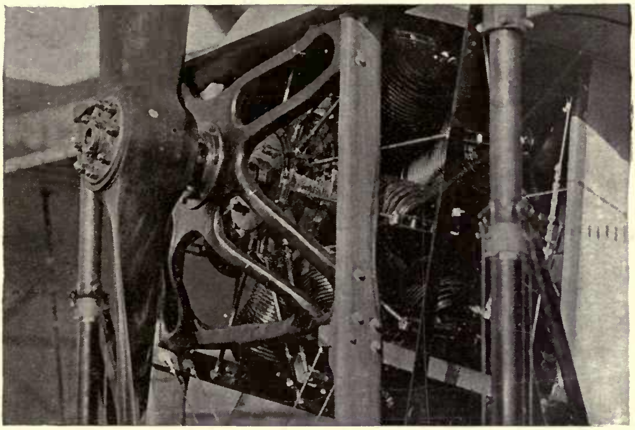
of the more recent aeroplanes of this type have been fitted with Gnome 50 horse-power rotary engines, similarly placed, and driving 7½ foot propellers.

The Seat is in the frame back of the main plane.

The Mounting consists of two large rubber-tired wheels at the front, mounted on an elastic chassis. The springs are made of thick rubber rope, and afford great elasticity and strength with small weight. There is also a small wheel at the rear.

Weight, Speed, Loading and Aspect Ratio.—

The total weight is from 650 to 720 pounds and the speed was at first 36 miles per hour; when a Gnome motor is used a speed



THE 14-CYL. 100-H. P. GNOME MOTOR OF CLAUDE GRAHAME-WHITE'S BLERIOT RACER WITH WHICH HE WON THE GORDON-BENNETT CUP RACE ON OCT. 29TH, 1910, AT BELMONT PARK

of 48 miles per hour is attained; 14.4 pounds are lifted per horse-power and 4.5 pounds carried per square foot of surface. The aspect ratio is 4.35 to 1.

The regular one-passenger type of this monoplane has further been altered to the new No. XI. *bis.* in which the sectional curvature of the planes is made very nearly flat on the underside. This change has been found to decrease the dynamic or drift resistance of the machine without seriously decreasing the lift. The speed

has been increased to about 52 miles an hour. The spread is 28½ feet and the area 160 square feet.

There are two new models of this macnine which have been very successful. They are the No. XI. *2bis.* a two or three-passenger machine, and the No. XI. racing model.

The No. XI. racing model (*type de course*) is the machine upon which Leblanc recently established the speed record of the world by flying at almost 69 miles an hour, and with which Grahame-White won the 1910 Gordon-Bennett Cup Race.

This machine has a very short body, flat planes, and a reinforced frame. The surface has been reduced to 129 square feet, and the machine is equipped with one of the new 14-cylinder 100 horse-power Gnome motors. The total weight is about 750 pounds. Only 7.5 pounds are carried per horse-power, and as much as 5.76 pounds are lifted per square foot of surface.

References.—Zeit. Ver. Deut. Ing., v. 53, p. 1574; Aeronautics, v. 5, p. 118; Aerophile, v. 17, pp. 102, 106, 129, 318, 488; Encycl. d'Av., v. 1, pp. 3, 72, 92; Flug. Motor Tech., N . 22, p. 10; No. 23, p. 7; No. 25, p. 14; Flight, v. 1, p. 45?; Boll. Soc. Aer. Ital., v. 6, p. 288; Locomocion Aerea, v. 1, p. 78; La Vie Auto, v. 9, p. 729; La Nature, v. 37, p. 325; SCI. AMERICAN SUP., v. 68, p. 136; Bracke, A., "Les Monoplans Blériot"; Glugsport, No. 24, p. 685; Genie Civil, v. 55, pp. 260, 344.

3. BLERIOT XI. 2 BIS

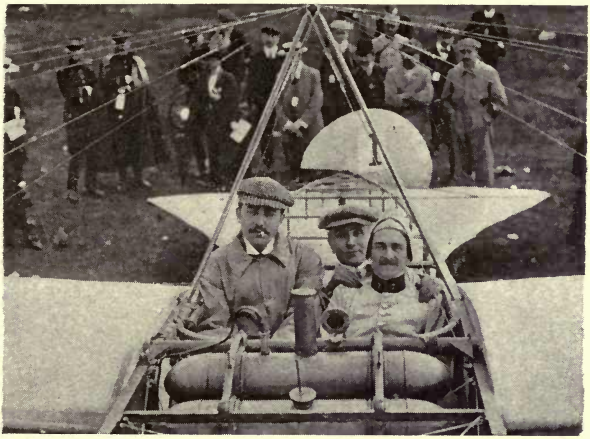
This machine, better known as the "type militaire," resembles in detail the other Blériot products, but differs greatly in size, in the fact that it is a two-seater, and in the construction of the fan-shaped tail.

Like all the new Blériot products, the dashboard in front of the seats is equipped with many of the new devices, such as recording barographs, speed counters, inclinators, folding map cases, speedometers, gages, and even thermos bottles, an equipment that indicates the rapid trend of progress in aviation more forcibly than anything else.

Many of the famous trips of the past year by Moisant (Paris to London), Morane, Drexel, and others, have been made on this type,

The Frame.—The frame is exactly similar in character to the Blériot XI. *bis* frame, excepting that it is shorter in length and built more heavily.

The Supporting Plane.—The plane is of the regulation Blériot type, fairly well arched (about 5 inches). The dihedral angle is very slight indeed. The halves are braced from the central *fuselage* and frame, in a slightly different manner than on the XI. *bis*. The plane has a spread of 36 feet. a chord of 7½ feet, and an area of 260 square feet.



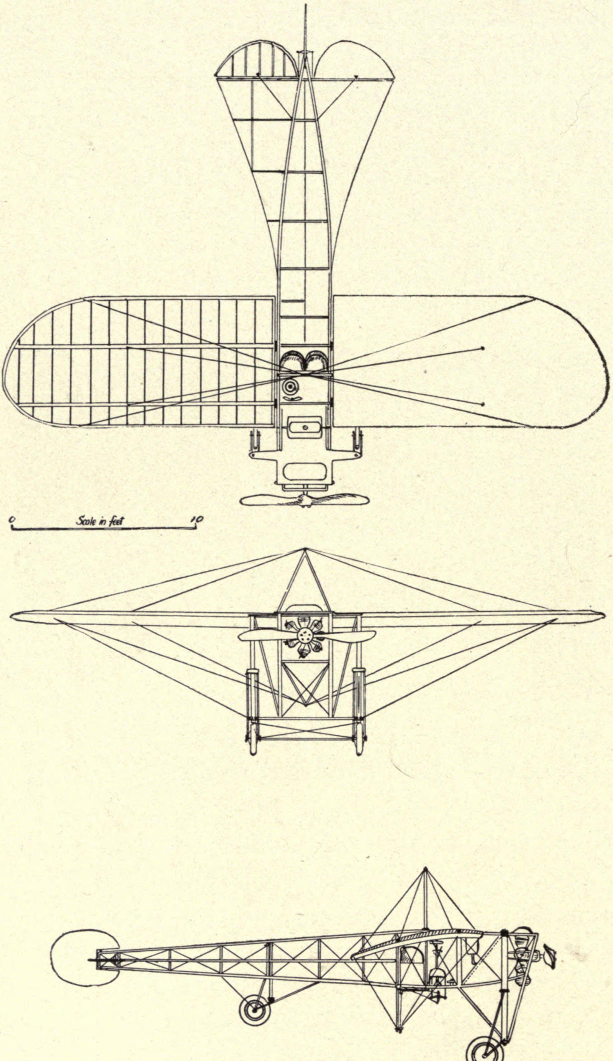
MORANE WITH TWO PASSENGERS ON HIS BLERIOT XI 2 BIS

Note the framing, the fan-tail and the direction rudder at the rear.

The Elevation Rudder.—The elevation rudder consists of two semicircular flaps, trailing on the end of the dovetail-shaped keel. It is operated by the *cloche* exactly as in the XI. *bis*.

The Direction Rudder.—The small oval-shaped vertical surface at the rear is the direction rudder. It is controlled as in other Blériot types.

Transverse Control.—The transverse equilibrium is, as usual in this make, controlled by warping the planes about their base.



The Bleriot XI 2 bis. Plan, Front Elevation and Side Elevation

Tail.—The curiously shaped tail on this machine gives it a remarkable bird-like appearance. It does not exert any considerable lift. The shape of the frame and tail on the No. XIV., flown by M. Blériot at Pau early in 1911, is quite different from the ordinary type. The frame itself narrows down, and gradually tapers into the form of the tail. The elevation rudder in this type is made of a single surface, and the direction rudder is in two halves, over and under the tail.

Propulsion.—A seven-cylinder Gnome motor drives a 7½-foot-diameter Regy propeller.

The *seats* for two are placed side by side in the frame between the two halves of the plane. In the very latest No. XIV. the seats are placed farther forward, and the frame in front built more in the form of a wind shield.

Mounting.—The mounting is on the usual Blériot wheel chassis at the front and a smaller wheel at the rear. The newest No. XIV. has a skid at the rear.

Weight, Speed, Loading and Aspect Ratio.—

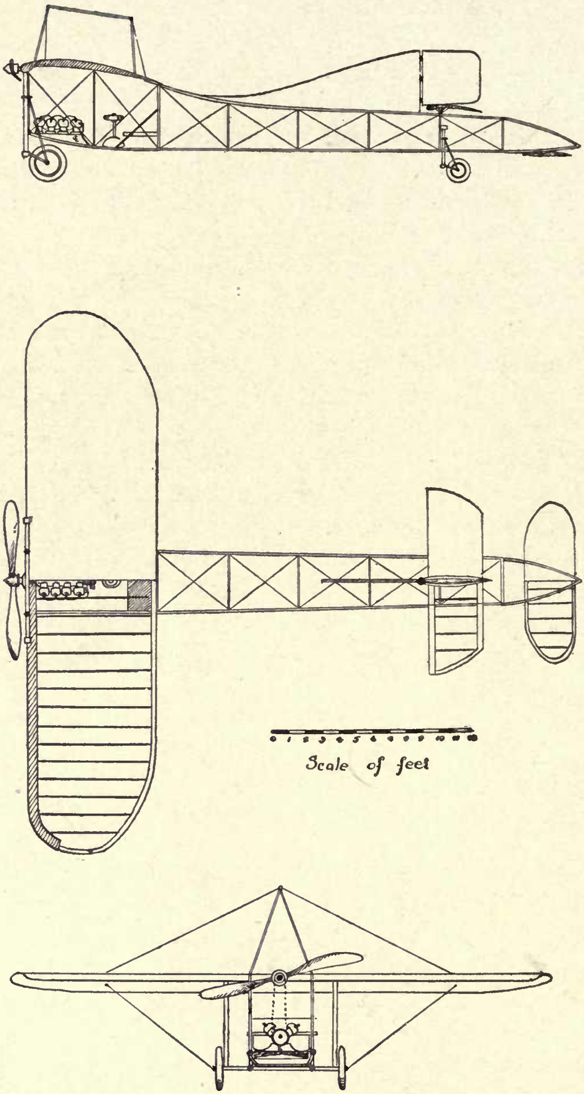
The total weight in flight is from 850 to 1,050 pounds. The speed is approximately 42 miles an hour; 21 pounds are lifted per horse-power, and 4.1 pounds carried per square foot of surface. The aspect ratio is 4.7 to 1.

References.—V. Quittner and A. Vorreiter, Zeit. für Flug. und Motorluft., November 26th, 1910; Aero, 1910, November 2nd, p. 350; Aircraft, December, 1910, p. 362; Flugsport, October 19th, 1910; L'Automobile, No. 338, 1910; Flight, 1910, October 22nd, p. 861; L'Aerophile, July 15th, 1910, p. 317.

4. THE BLÉRIOT XII. MONOPLANE

M. Blériot has also designed a passenger-carrying type of monoplane, the No. XII., which differs in structure from the No. XI. A type similar in form to the No. XII. is the small No. XIII., with which M. Blériot attained high speed at Rheims in 1909.

On June 12th, 1909, the first flight of an aeroplane carrying three passengers was accomplished by M. Blériot on his large No. XII. The machine at one time became popular, and more than ten aeroplanes of this type were flown.



THE BLERIOT XII. SIDE ELEVATION, PLAN AND FRONT ELEVATION

The Frame.—The long central frame of wood braced in every panel by cross wires is very deep at the front and tapers gracefully to a point at the rear.

GRAHAME-WHITE ON A BLERIOT XII.
The regulation *cloche* and foot-bar are clearly visible.

The Supporting Plane.—On the upper deck of the central frame at the front is placed the main plane, which is continuous and perfectly horizontal. The plane is braced by wires from the frame and its structure is similar to that of the Blériot No. XI. The spread is 30.2 feet, the depth is 7.6 feet, and the surface area is 228 square feet.

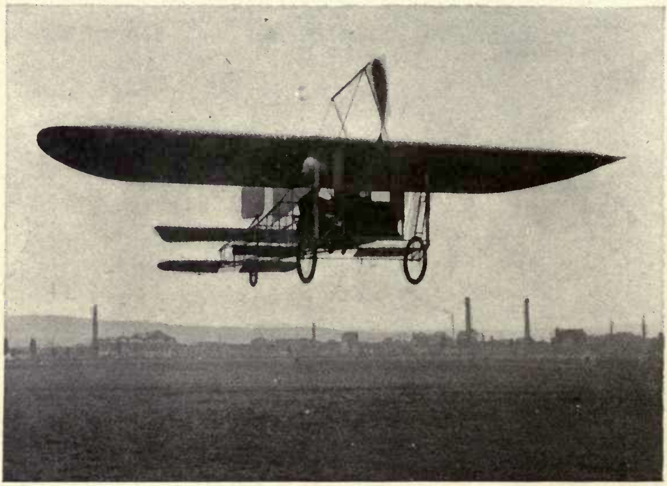
The Direction Rudder.—A single surface placed at the rear extremity of the vertical keel is used as the direction rudder. Its area is 9 square feet and it is operated by a foot lever as in No. XI.

The Elevation Rudder.—The elevation rudder consists of a single surface, placed at the extreme rear and 20 square feet in area. It is operated by the front and back motion of the *cloche.*

Transverse Control.—To preserve the lateral balance the main surface is warped inversely by the side-to-side motion of the *cloche,*

exactly as in No. XI. A small surface under the seat also aids in lateral balancing.

Keels.—A horizontal keel of 21 square feet area is placed on the framework at the rear, but somewhat in front of the elevation rudder.



THE BLERIOT XII. IN FLIGHT.

Propulsion.—A 60 horse-power 8-cylinder E. N. V. motor is placed in the frame under the main plane. This motor drives by a chain transmission a single 2-bladed Chauviere propeller, the axis of which is placed on the edge of the main plane. This propeller is 8.8 feet in diameter and 9 feet pitch, and turns at 600 r.p.m.

The Seat or bench for three is placed in the frame under the main plane and back of the motor.

The Mounting is similar to that on No. XI.

Weight, Speed, Loading and Aspect Ratio.—

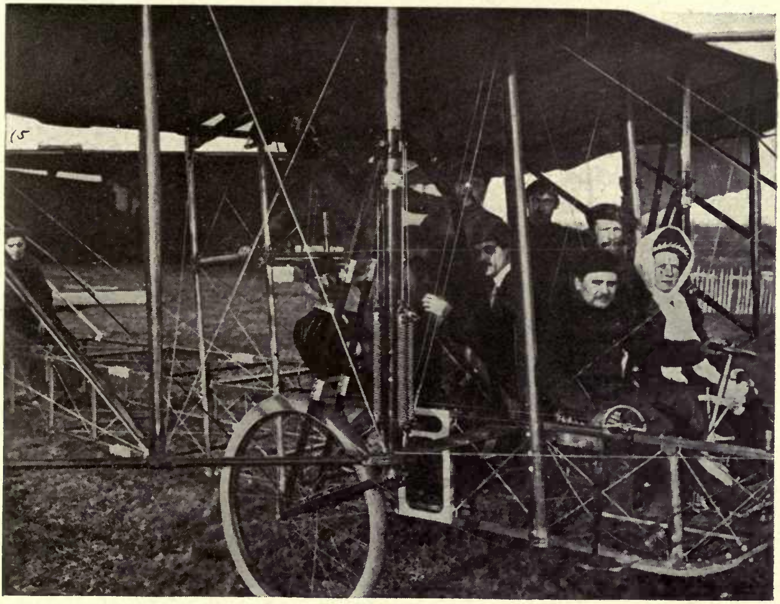
The total weight is from 1,150 to 1,300 pounds. The speed

is 48 miles per hour; 21 pounds are lifted per horse-power and 5.3 pounds per square foot of surface. The aspect ratio is 4 to 1.

References.—Aerophile, v. 17, pp. 319, 488; SCI. AMERICAN SUP., v. 68, p. 136; Encyl. d'Av., v. 1, pp. 72, 92; Flug. Motor Tech., No. 20, p. 18; No. 22, p. 10; La Vie Auto, v. 9, p. 729; Locomocion Aerea, v. 1, p. 28; Aeronautics (Brit.), v. 2, p. 117; L'Automobile, v. 7, p. 520; Genie Civil, v. 55, p. 344.

5. THE BLERIOT "AERO-BUS"

The four-seater Blériot "Aero-bus," first flown in February, 1911, at Pau, is a very marked departure from the usual Blériot types.



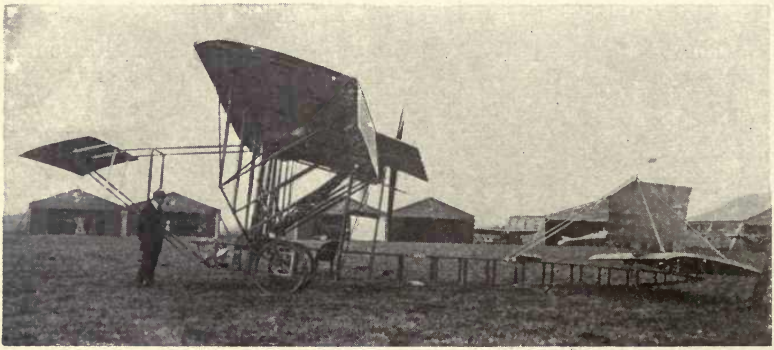
THE BLÉRIOT "AERO-BUS"

Eight passengers at the front and one at the rear about to start a flight. Le Martin, the pilot, has hold of the cloche.

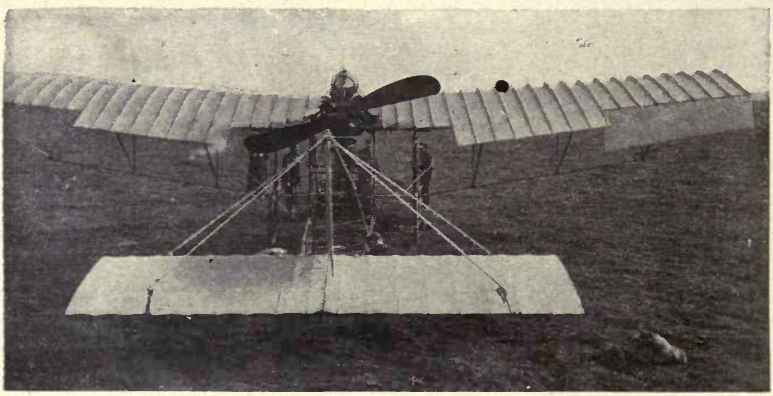
The passengers sit under the main plane, as on the old No. XII, and as many as nine passengers have been carried with ease.

The accompanying photographs give an excellent idea of the framing and disposition of parts. The huge propeller, 10 feet in diameter, is driven by a 100 horse-power Gnome motor equipment.

The front elevation rudder and ailerons for transverse control bear distinct resemblance to the Farman biplanes. The practical



SIDE VIEW OF THE BLÉRIOT "AERO-BUS"

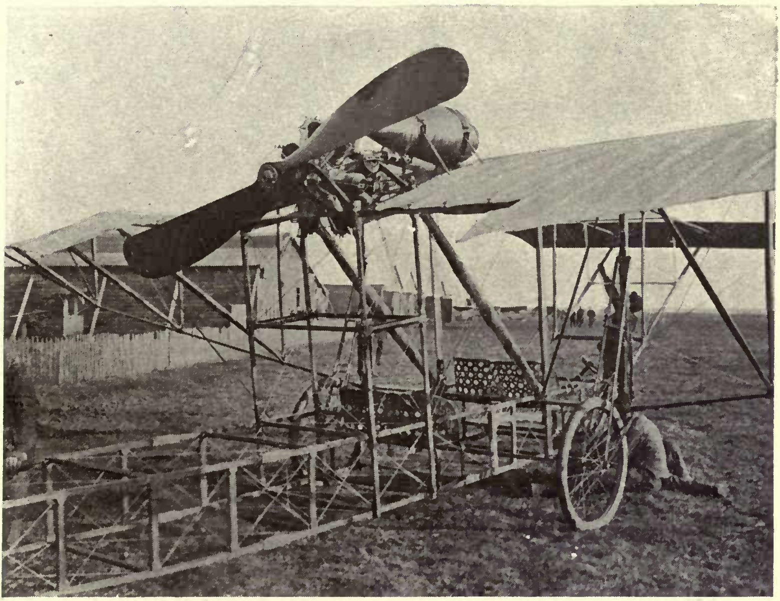


REAR VIEW OF THE BLÉRIOT "AERO-BUS"

The deep ribs are clearly shown in this photograph, as are also the ailerons.

elimination of cross-wires in the main framing and bracing of the planes on this type is a constructional detail that is worthy of note.

The spread of this machine is 43 feet and the surface area 430 square feet.



DETAIL VIEW OF THE BLÉRIOT "AERO-BUS"

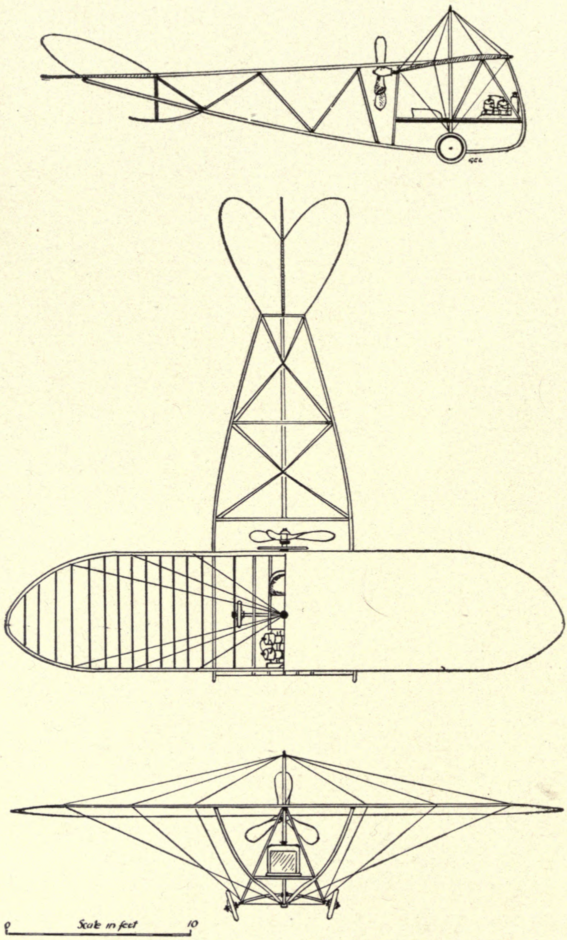
The propeller, motor, and gasolene tank are grouped above and supported on strong framework.

The weight, empty, is 1,323 pounds, and the maximum "live load" carried is about 1,100 pounds; 24.25 pounds are lifted per horse-power and 5.63 pounds per square foot of surface.

6. THE DORNER MONOPLANE

The progress in Germany during 1910 was by no means restricted to imitating the French, as commonly supposed, but on

the contrary many interesting and distinctive types of aeroplanes were evolved. Among these one of the most successful is the Dorner monoplane. This type resembles the v. Pischof more than any other. The weight carried per horse-power and the speed attained are high.



THE DORNER MONOPLANE. SIDE ELEVATION, PLAN AND FRONT ELEVATION

The Frame.—A triangular frame, wide and deep at the front, and the lower main member of which is projected out forward, serving as a skid, narrows to a point at the rear. The frame has not many cross wires, since inclined struts are used for giving the required rigidity. The entire length of the machine is 34 feet.

The Supporting Plane.—The main plane is perfectly horizontal and continuous as on the old Blériot XII. It is rounded at the ends and warpable. The spread is 38 feet, the chord 8¼ feet, and the surface area 280 square feet. The plane is braced from a central mast.

The Elevation Rudder.—The dove-like shaped tail, 60 square feet in area, is very flexible and is bent as on the Grade. The control is by means of a lever in the aviator's left hand, which when pushed forward bends the tail down and causes descent and when pulled back causes ascent.

The Direction Rudder.—A single flexible 16 square foot surface at the rear over the horizontal tail serves as the direction rudder. It is bent over to either side by means of a lever in the aviator's right hand.

Transverse Control.—The main surface is warped by the feet acting on pedals as on some of the latest French biplanes.

Tail.—The gracefulness and simplicity of the tail on the Dorner is quite in contrast to the complicated structure on the Pischof, the rudders themselves, when not in use, acting as a stabilizing *empennage.*

Propulsion.—The radiator and four-cylinder 22 horse-power water-cooled Dorner motor are placed in front of the two seats, all under the lower plane, as on the Blériot XII. and Pischof. The motor drives by chain a three-bladed wood and metal Dorner propeller, 8.4 feet diameter and 6½ feet pitch, at 670 r.p.m. The propeller is placed on a level with the entering edge of the main plane, at the rear.

Mounting.—The mounting is mainly on two rubber-tired wheels, and the main central skid at the front, with also a small skid at the rear.

Weight, Speed, Loading and Aspect Ratio.—

The speed is 50 miles an hour. The total weight is from 770 to 940 pounds; as much as 39 pounds are carried per horse-power, and 3 per square foot of surface. The aspect ratio is 4.6 to 1.

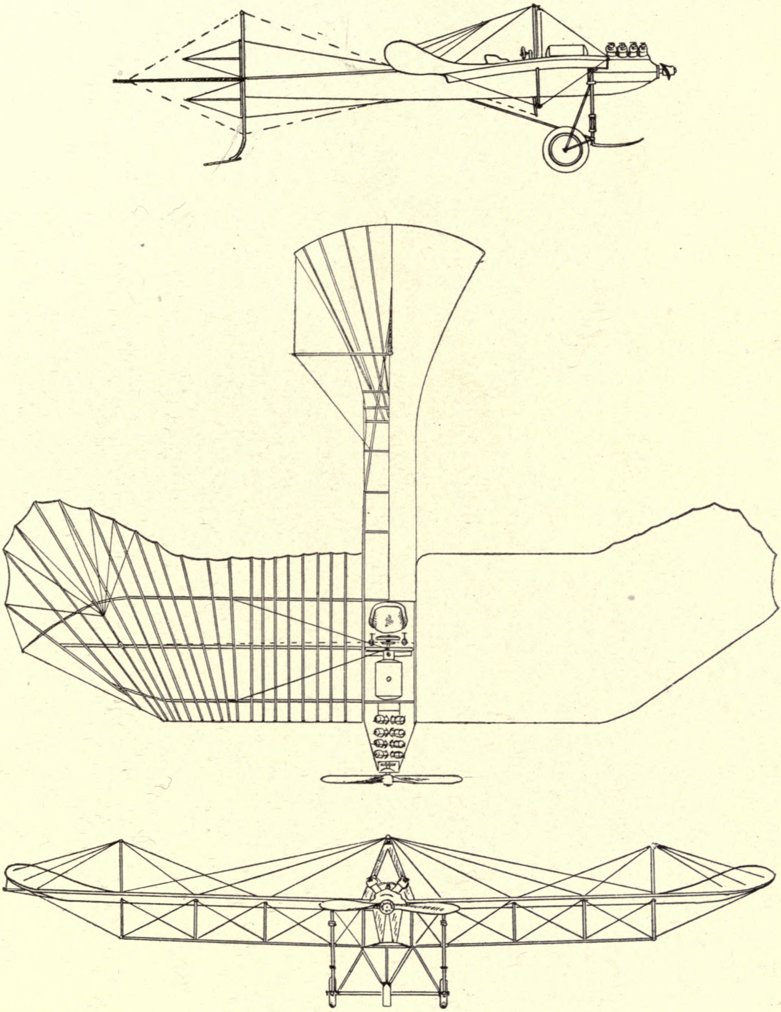
References.—Vorreiter, A. "Jahrbuch, 1911," p. 111; Zeit. für Luftschiff, No. 2, 1910; Zeit. für Flug. u Motorluft., September 24th, 1910; L'Aerophile, December 15th, 1910, p. 559.

7. THE ETRICH MONOPLANE

In Austria, the progress of aviation during the past few years has been closely bound up with the efforts of Igo Etrich and his associate, Herr Wels. Many years ago they began experimenting on lines laid down by the famous Austrian pioneer, Kress, whose work, more or less contemporaneous with Maxim, Langley, Renard, and Lilienthal, is well known. In 1906 they experimented successfully with a glider at Oberaltstadt, Bohemia. After having built many experimental machines at a time when motors were the cause of so much trouble to prospective aviators, Etrich and Wels finally evolved a somewhat successful type of monoplane in the early part of 1908. This machine, named by them the "Etrich-Wels III.," was substantially the same as the present-day type, excepting that it was equipped with a front elevation rudder which was later discarded.

During 1910, along with the progress elsewhere, Austria, represented by the Etrich IV. and the Warcholovski biplane (also designed by Etrich), jumped to the fore. Illner, one of the best Etrich monoplane pilots, flew from Steinfelde to Vienna across country on May 17, 1910; made an 80-kilometer cross-country flight on October 6th, 1910; flew from Vienna to Horn and back, a distance of 160 kilometers, four days later; and in the last week of the same month made a magnificent duration flight of over two hours. Aman has flown the Etrich well in France, and at Johannisthal (Berlin) the new Etrich-Rumpler made an excellent showing. The career of the Etrich, in fact, has been so brilliant that the Austrian Minister of War is said to have ordered twenty of this type for the army.

The Frame.—The frame of this machine is quite original. The main bracing of the plane consists of a single panel of



THE ETRICH MONOPLANE. SIDE ELEVATION, PLAN AND FRONT ELEVATION

wire trussing and struts, very much as on a biplane, and placed laterally under the main plane. There is a central *fuselage,* and central struts as well as large struts at the outer end of each wing from which the plane is braced by a great number of wires. The entire construction reminds one of the old Lilienthal machines, and is in fact a distinct development of them, Etrich having the distinction of possessing one of these famous gliders. It is evident in the frame work and construction of the entire machine that the structure of a bird's wing has been very carefully studied, many features of the ribs, etc., resembling the feathers of a bird. Steel tubing and fine wood and cross-wire construction is used profusely throughout the frame.

The Supporting Plane.—The plane is shaped like a bird's wing and is tipped up at the rear ends, a device for stability that was suggested by Victor Tatin as well as by Lilienthal and that is also used on the Pischof monoplane. The halves are at a small dihedral angle as well. The sectional curvature is of the well-known Lilienthal bird-like form. The spread is 46 feet, the maximum chord is 9¾ feet, and the area 344 square feet. The ends have a depth of over 12 feet.

The Elevation Rudder.—At the rear is a very bird-like tail, the trailing edge of the horizontal *empennage* being moved up or down for ascent or descent. The control is by means of a column which is pivoted to move backward and forward, a forward push turning the tail down, etc. The rear horizontal *empennage* and tail is 14 feet long by 11 feet wide.

The Direction Rudder.—Two triangular surfaces are used, very much resembling the Antoinette. Rectangular surfaces are also sometimes used. They are operated by the two foot pedals. To turn to the right, for example, the left pedal is pressed down and the right up. This turns the rudder and at the same time turns the front wheels out to the left. The opposite control has also been employed occasionally, i. e., the right pedal pressed down for a turn to the right.

Transverse Control.—Warping of the wings is used for transverse control; the mechanism accomplishing it consists of wire and

pulley connections to the steering wheel mounted on the control column. By turning the wheel clockwise, the left side is turned down and therefore lifts up, while the right is turned up and therefore sinks. The entire rear edge of the wing is flexible. The warping alone, however, is not supposed to be entirely responsible for the lateral movement. The rear turned-up ends are so curved that when warped up considerably. they form a pocket, very much like the blade of a turbine, which catches the air, and slows down that side. The other side then flies around and due to its higher speed and consequent increase of lift, cants up greatly. The result is that turns of such sharp curvature can be made, that the machine appears merely to pivot around the inside wing.

Tail.—The bird-like tail has vertical and horizontal *empennages.* The entire body is inclosed and shaped fusiform, adding still more to the bird-like appearance.

Propulsion.—Formerly a Clerget four-cylinder 50 horse-power motor, mounted at the front as on the Antoinette, was used, but of late both Rumpler eight-cylinder 55 horse-power and Austrian Daimler four-cylinder 65 horse-power motors have been used. The propeller is a Chauvière, 7.2 feet in diameter, 4 feet pitch, and rotates at 1,400 r.p.m.

The Mounting.—The mounting chassis resembles somewhat the Blériot. On the newest machines a large front skid has also been fitted. There is a small skid at the rear.

The *seat* is placed about in the center of the main plane, and is well protected from the exhaust, slip stream of the propeller, etc.

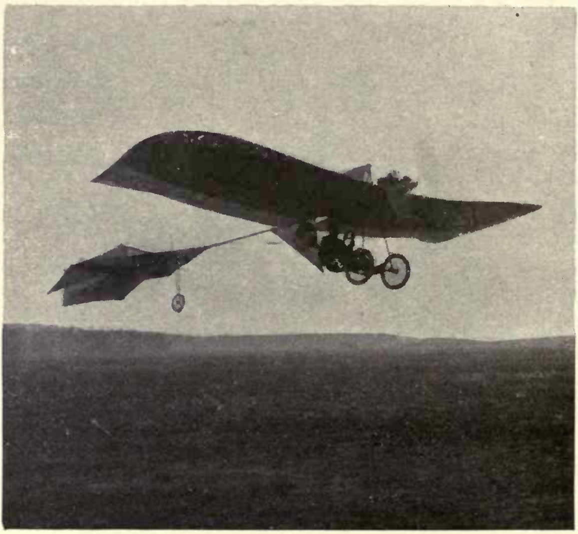
Speed, Weight, Loading and Aspect Ratio.—

The speed is 51 miles an hour. The total weight in flight is 1,100 pounds; 20 pounds are lifted per horse-power, and 3.2 pounds per square foot of surface. The aspect ratio is 4.72 to 1.

References.—Fachzeit. für Flug., October 16th, 1910, p. 15; November 13th, 1910, p. 23; L'Aerophile, March 1st, 1908, p. 80; June 15th, 1910, p. 271; December 15th, 1910, p. 559; Allge. Auto. Zeit., October 16th, 1910; Aircraft, November, 1910, p. 325; Flugsport, October 5th, 1910, p. 602; Flight, May 14th, 1910; Aero, November 30th, 1910, p. 428; La Conquete de l'Air, September 15th, 1910.

8. THE GRADE MONOPLANE

Herr Grade has the distinction of being one of the first German aviators to design and successfully fly an aeroplane. In the fall of 1909 he began flights on his interesting monoplane, and on October 30th, 1909, won the $10,000 Lanz prize for a German-built machine. Since then Herr Grade has made many excellent flights, and in the recent race meeting at Heliopolis he took a notable part. His machine is simple and flies easily. Many duplicates of this type have been sold. Among those who have flown this type are Rode, Treitschke and Plochman, who was later killed on an Aviatik biplane.



THE GRADE MONOPLANE IN FLIGHT

The Frame.—The frame consists essentially of a main metal tube chassis at the front, from which a long, thick piece, supporting the rudders is run out to the rear.

It is remarkable for its simplicity.

The Supporting Plane.—The main surface is made of Metzeler

rubber fabric stretched over a bamboo frame. The surface is very flexible and the two ends are slightly turned up from the center. The curvature is almost the arc of a circle and the surface is very thin. The spread is 33 feet, the depth 8.5 feet, and the area 270 square feet.

The Direction Rudder.—The direction rudder consists of a single flexible surface of about 16 square feet area, carried at the rear and controlled by a lever operated by the aviator. The surface is not hinged, but is merely bent by the controlling wires in the desired way.

The Elevation Rudder.—The elevation rudder consists also of a single flexible surface placed at the rear. Its area is about 20 square feet and it is operated by a large lever universally pivoted on the frame above the aviator. To rise, this lever is pulled up, and to descend, it is pushed down, thus respectively bending up and bending down the rear horizontal surface.

Transverse Control.—The transverse control is effected by warping the main surfaces. This is accomplished through wires leading from the large lever previously referred to. Side to side motion of this lever warps the surfaces inversely. Thus if the machine tips down on the right, the lever is moved over to the left, thus raising the depressed side and depressing the elevated side.

Keels.—The tapering ends of both the direction and elevation rudders can be considered as keels. An additional vertical keel is placed in front, both above and below the main surface.

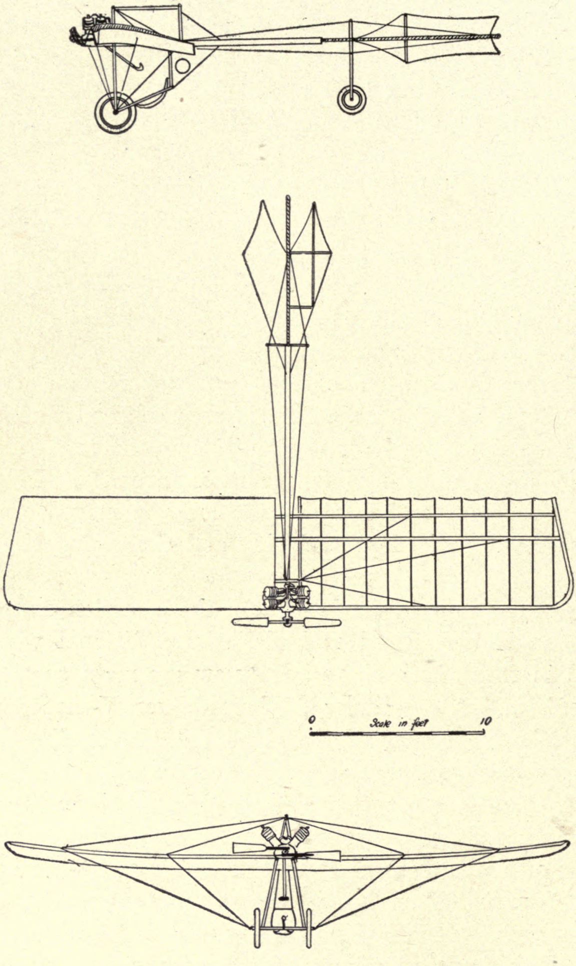
Propulsion.—A 4-cylinder 24 horse-power V-shaped motor is placed at the front edge of the plane. It drives direct at 1,000 r.p.m. a 2-bladed metal propeller 6 feet in diameter and 4 feet pitch. A Chauviere propeller has also recently been fitted.

The Seat is placed under the plane, and consists of a hammock-like piece of cloth which gives great comfort and little weight.

The Mounting is on two wheels at the front and one smaller one at the rear. There are no springs provided whatsoever on the chassis. The front wheels are fitted with a rake to bring the machine to a stop shortly after landing.

Weight, Speed, Loading and Aspect Ratio.—

The total weight is from 400 to 500 pounds. The speed is approximately 52 miles per hour; 17 pounds are lifted per horse-



THE GRADE MONOPLANE. SIDE ELEVATION, PLAN AND FRONT ELEVATION

power and 2.0 pounds per square foot of surface. The aspect ratio is 3.9 to 1.

References.—Sci. American, v. 101, p. 292; Aerophile, v. 17, pp. 439, 508; Zeit. für Luftschiff, v. 13, pp. 802, 957; Aero, v. 1, p. 405; Motor Car Jour., v. 2, p. 794; La Vie Auto, v. 9, p. 711; Zeit. Ver. Deut. Ing., v. 53, p. 1762.

9. THE HANRIOT MONOPLANE

The Hanriot monoplane is a very recent type, with which excellent results have been obtained. It does not in any way depart radically from the regulation monoplane lines, but differs largely in structural details and dimensions. Vidart, Wagner, Marcel Hanriot, and Deletang, are some of the noted pilots of this exquisitely graceful machine.

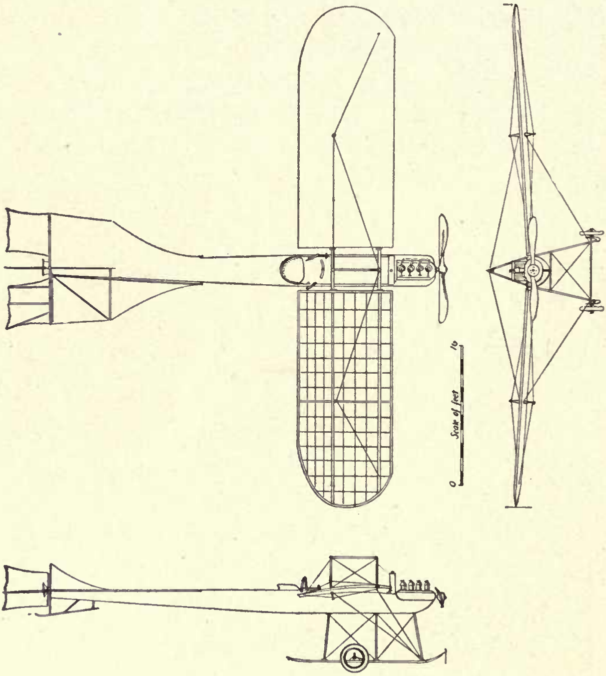
Control Lever and Seat of the Hanriot

A photograph of the Hanriot in flight is given in the frontispiece.

The Frame.—The general appearance of the Hanriot is very trim and shipshape. The central *fuselage* is built like a racing skull, and is very light and strong. This construction does away with the large amount of cross-wires, etc. The main spars for the planes are made of wood in three layers and are 3 inches deep

and 1½ wide. The skids are fixed at the bottom of an A-type frame, the upper part of the A forming a triangular frame above the planes, to which the latter are fastened by stout wires.

The Supporting Plane.—The plane is divided in half. The halves are braced from the central frame, and set at a slight dihedral angle. Their corners are rounded. The section is medium-



PLAN AND ELEVATION OF THE HANRIOT ONE-PASSENGER MONOPLANE

ly thick and rather evenly curved, the greatest camber being near the center. The spread is 29½ feet, the depth 7 feet, and the surface area 183 square feet.

The Elevation Rudder.—Hinged to the rear of the horizontal tail are two flaps serving as the elevation rudder. All the rud-

ders in the Hanriot are noteworthy for their small size. These rudders are operated by a lever in the aviator's right hand, which is pushed forward for descent and pulled in for ascent. The rudders are 2 feet deep.

The Direction Rudder.—A very small single surface, placed between the two elevation rudder flaps, is the direction rudder. It is operated by a foot bar, as on many of the French monoplanes.

Transverse Control.—Warping of the planes is used for transverse control. The rear spars are hinged, to permit of this. The lever controlling this is in the aviator's left hand, and when pulled to the right, elevates the left side of the machine. The control system is described in Chapter XIII.

Tail.—The horizontal *empennage,* non-lifting, resembles very much that on the Antoinette. A small triangular vertical *empennage* placed above the horizontal one is provided. The tail surface, however, is remarkable for its small size. The skiff-like frame does not come to a point on this type, although on the larger type it does. The total length is 26 feet. The tail is 8 feet wide, and in all 9 feet long.

Propulsion.—A four-cylinder 50 horse-power Clerget is usually provided and drives at 1,200 r.p.m.; a Chauvière propeller, 7.2 feet in diameter and 3.8 feet pitch, is placed about 3 feet in front of the main plane. An eight-cylinder E. N. V. 40 horse-power motor is also used.

The *Seat* is placed as in the Antoinette, and is very comfortable.

Mounting.—The mounting is mainly on two strong skids at the front supported by three uprights of the A-type frame work; the axles of the two wheels are carried on vertical guides, and are suspended by rubber springs anchored to the skids. There is a small skid at the rear.

Speed, Weight, Loading and Aspect Ratio.—

The speed is approximately 51 miles per hour. The total weight is 760 pounds; 15.2 pounds being lifted per horse-power, and 4.15 per unit of surface. The aspect ratio is 4.2 to 1.

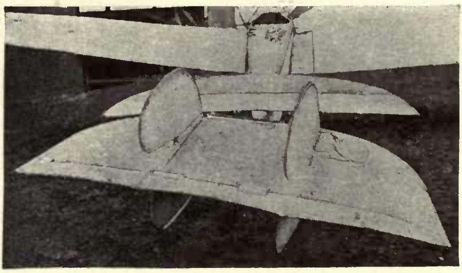
There is a larger passenger-carrying type of this machine in

which the spread is 43 feet and the surface 300 square feet. The total weight is 1,120 pounds, and the speed somewhat less than the small type.

References.—Aero, 1910, November 2nd, p. 350; October 12th, 1910, p. 291; Aeronautics (Brit.), September, 1910, p. 126; L'Aerophile, July 15th, 1910, p. 317; V. Quittner and A. Vorreiter, Zeit. für Flug. u Motor., November 26th, 1910; Flight, 1909, November 20th, p. 740; Flight, 1910, December 3rd, p. 986.

10. THE NIEUPORT MONOPLANE

This extraordinary monoplane attracted a great deal of attention abroad during 1910 by its repeated flights at a speed of 52½ miles an hour with a small 18 to 20 horse-power engine. It is noted for the extreme simplicity of its design and the finish ex-

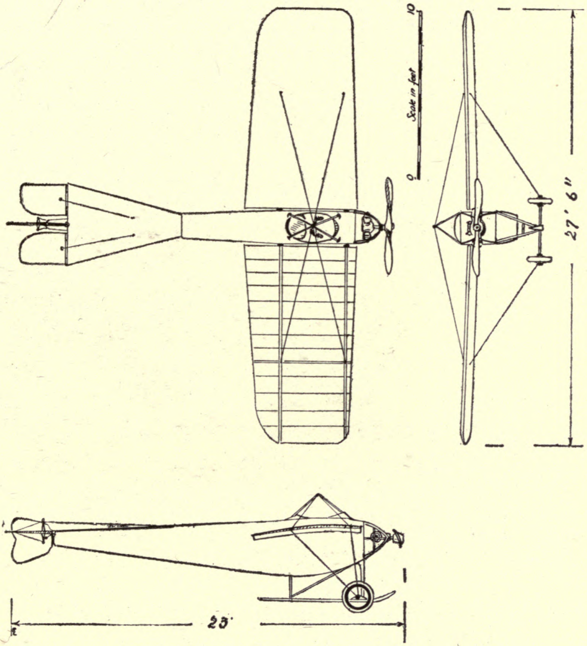


VIEW OF THE 1910 NIEUPORT MONOPLANE FROM BEHIND, SHOWING THE TAIL, FISH-LIKE BODY, AND WINGS

hibited in its structure. It resembles more the new R. E. P. monoplane than any other type, but is much smaller. An unusual feature is the almost complete manner in which the aviator is inclosed in the large fusiform hull. At Rheims in 1910 this type was flown by Niel, Nogues, and Nieuport.

The Frame.—The central framework is of wood, steel tube, and steel wire construction; and is completely inclosed except the seating space for the aviator.

The Supporting Plane.—The plane is very strongly built and is divided into two halves, each braced by only four cables from the central frame. The sectional curvature is quite flat and of even thickness. The head resistance of the framing, planes, and body, due principally to the reduction in the number of cross wires, is extremely low. The supporting plane has a spread of 27½ feet, a maximum chord of 6½ feet, and an area of 150 square feet.



PLAN AND ELEVATIONS OF THE ONE-PASSENGER 20-H. P. NIEUPORT MONOPLANE

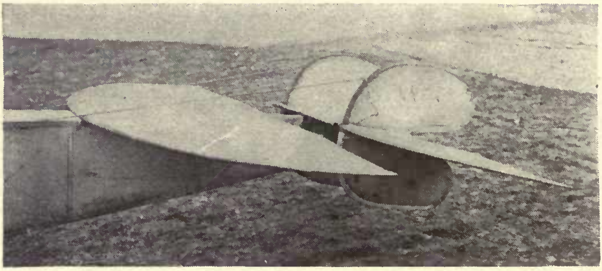
The Elevation Rudder.—At the rear are the rudders, the two small horizontal surfaces serving to control the elevation. They are manipulated by the forward and back motion of the steering column as generally installed on French machines.

The Direction Rudder.—A small vertical surface at the rear

between the two flaps of the elevation rudder, as on the Hanriot, is the direction rudder. It is operated by turning the steering wheel mounted on the control column. A biplane direction rudder was formerly used, but has been discarded.

Transverse Control.—The planes are warped in the usual manner, the control being by foot pedals as on the M. Farman and Voisin "Bordeaux," a type of control which is now coming into general use abroad.

Tail.—A bird-like tail, consisting of a tapering horizontal *empennage,* is provided. There is no vertical *empennage,* but the vertical sides of the large inclosed body fulfill this purpose. A horizontal lifting tail is provided on some of the types.



THE TAIL OF THE 1910 NIEUPORT MONOPLANE

On recent types, only one surface is used for steering; the elevation rudder consists of two small flaps and the keel shown here is discarded.

Propulsion.—One of the most interesting features of the Nieuport is the manner in which the two-cylinder Darracq 18 to 20 horse-power motor is mounted. The front spars of the frame project out beyond the inclosed body, and are joined together on either side by a steel joint. On the end of each cylinder is a pressed steel ring. These rings are fitted on the projecting steel joint end of the spars, and the motor there suspended. The motor drives direct a two-bladed Chauvière propeller, 6½ feet in diameter, 4 feet pitch, at 1,200 r.p.m.

The *Seat* is placed about on the center line of the planes, the aviator's head being flush with the top of the body.

The *Mounting* is mainly on two wheels, with a strong, springy axle, and a large skid at the center.

Speed, Weight, Loading and Aspect Ratio.—

The speed is 52½ miles an hour. The total weight is 670 pounds; 35 pounds are lifted per horse-power, and 4.5 pounds per square foot of surface. The aspect ratio is 4.23 to 1.

There is a two-passenger type of this machine, 34 feet spread, and having an area of 194 square feet. The total weight is about 860 pounds, and a Gnome 50 horse-power motor is used.

References.—Aero, 1910, November 2nd, p. 350; November 30th, p. 425; Flight, July 16th, 1910, p. 551; December 10th, 1910; Aerophile, July 15th, 1910, p. 317; Vorreiter, A. "Jahrbuch, 1911."

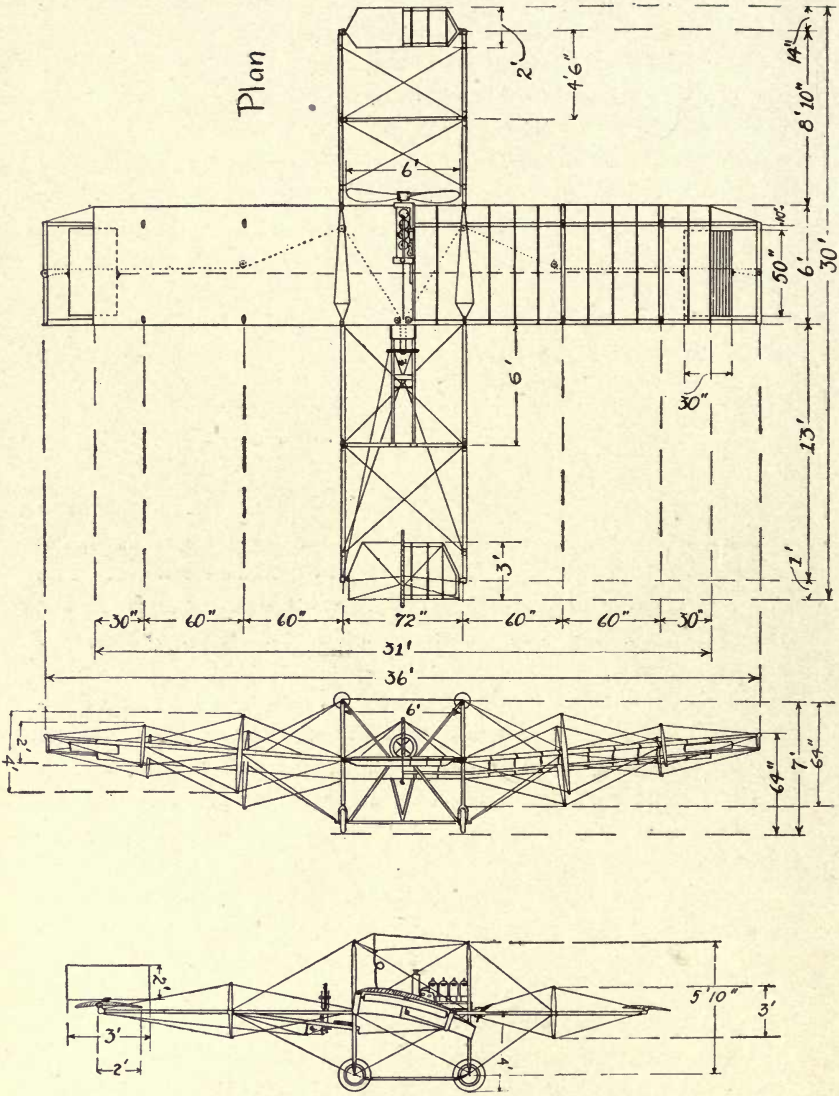
11. THE PFITZNER MONOPLANE

In the early part of January, 1910, the monoplane designed by Mr. A. L. Pfitzner and built at the Curtiss aeroplane factory at Hammondsport, N. Y., was completed and flown. The first flights were short, due largely to the inexperience of the aviator, Mr. Pfitzner, but the monoplane is considered by many to be a very promising type.

This aeroplane is a distinct departure from all other monoplanes in the placing of the motor, aviator, and rudders, and in the comparatively simple and efficient method of transverse control by sliding surfaces, applied here for the first time.

The Frame.—The framework is largely a combination of numerous king-post trusses with spruce compression members and wire tension members. The framework is open throughout, thus enabling quick inspection and easy repairs. The chassis at the center is mainly of steel tubing.

The Supporting Plane.—The main supporting plane at a 5-deg. dihedral angle consists of two main beams across which are placed spruce ribs. The surface is made of Baldwin vulcanized silk, of jet black color, tacked to the top of the ribs and laced to the frame. The curvature of the surface is slight and is designed

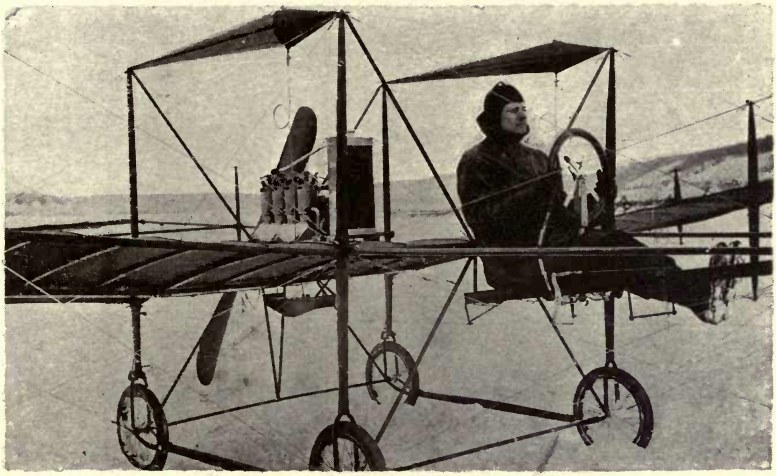


PLAN AND ELEVATIONS OF THE PFITZNER MONOPLANE

for high speed. The spread is 31 feet, the depth 6 feet, and the surface area 186 square feet.

The Direction Rudder.—The direction rudder, a rectangular surface, is placed at the front and has an area of 6 square feet. It is operated by wires leading to the bracket underneath the controlling column. By turning this column to either side the aeroplane turns to that side.

The Elevation Rudder.—The elevation rudder consists of a single surface 17 square feet in area placed also at the front. It is operated by wires leading to the lever at the side of the con-



THE PFITZNER MONOPLANE

A near view of the chassis, motor and controls.

trolling column. By moving this column forward or backward, the elevation rudder is caused to turn down or turn up respectively.

Transverse Control.—The framework of the main surface is carried out 30 inches on either end of the surface, and affords a place for the rail upon which the auxiliary sliding surfaces move. These sliding surfaces, or "equalizers" are each 12½ square feet in area, and when normal project 15 inches beyond the end of

the surface on either side. They are connected by a wire to each other, and a long cable running to each end through a pulley connects them to the steering wheel. The control is then as follows: If the right end of the aeroplane is tipped down, the wheel supported on the controlling column is turned away from the lowered side. This causes the equalizer on the raised end to be pulled in under the main surface, while at the same time the one on the other end is pulled out. This action merely decreases the supporting surface on the raised end and increases that on the lowered end, thus righting the machine.

Keels.—A horizontal surface placed at the rear acts as a longitudinal stabilizer. It is 10.5 square feet in area, and is fixed firmly to the supporting framework, 10 feet in the rear of the main surface.

Propulsion.—A 25 horse-power Curtiss 4-cylinder motor is placed on the framework above the plane and at the rear of it. The motor drives direct a 2-bladed wooden propeller 6 feet in diameter and 4.5 feet pitch at 1,200 r.p.m. The propeller is of original design and said to be very efficient.

The Seat for the aviator is placed out in front of the main plane and directly on the center line.

The Mounting is on four small rubber-tired wheels, placed at the lower ends of the four main vertical posts of the chassis. The wheels are not mounted on springs. They are spaced by steel tubing and are fitted with brakes.

Weight, Speed, Loading and Aspect Ratio.—

The total weight in flight is from 560 to 600 pounds. The speed is estimated at 42 miles per hour; 24 pounds are lifted per horse-power, and 3.2 pounds carried per square foot of surface. The aspect ratio is 5.17 to 1.

References.—Aeronautics, v. 6, p. 53, February, 1910; v. 6, p. 82, March, 1910.

12. THE PISCHOF MONOPLANE (AUSTRIAN)

This monoplane is a distinct departure from usual practice, and is particularly notable for the position of its propeller, its

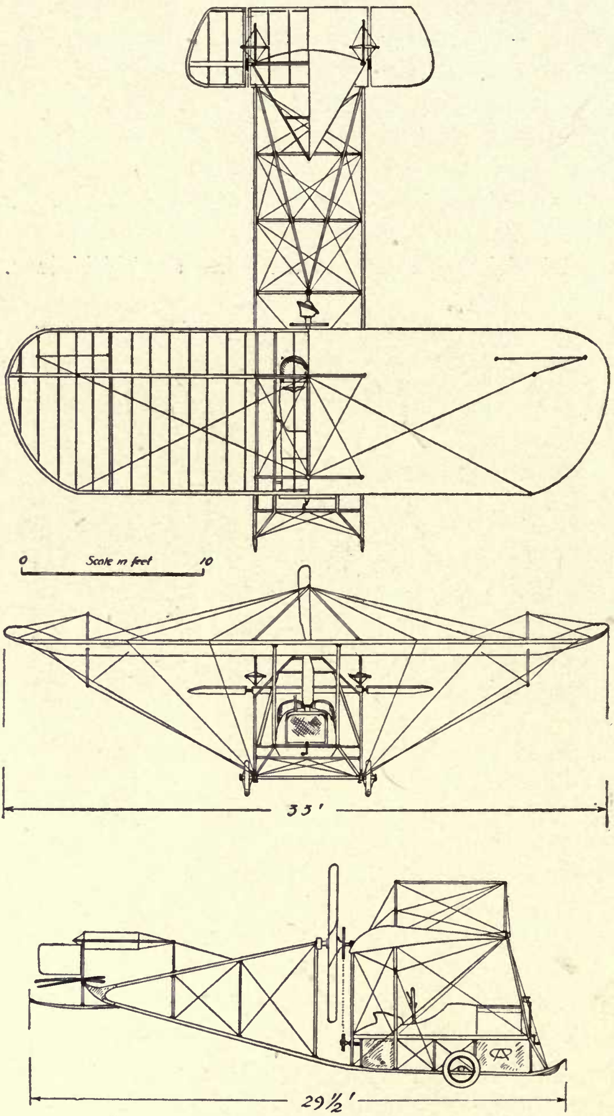
low center of gravity, the upturned ends of the plane, and the provision of a clutch enabling the aviator to start the motor, step into the machine, and then start the propeller. Many biplanes and monoplanes were built by M. Pischof in 1907 and 1908. The present type, with its chassis like a motor car, has been flown very well this summer, and certainly incorporates many practical and far-sighted innovations. Despite its low center of gravity, it flies easily around corners. This type is manufactured by the Autoplan-Werke in Vienna, as is also the Warchalowski biplane.

THE PISCHOF MONOPLANE

A view of the body, showing the automobile-like radiator and motor casing, the crank and the propeller which is governed by a clutch.

The Frame.—The wooden cross-wired frame is everywhere painted with an aluminum mixture, as were the Wright machines. The joints are very strong, and the lower members are continued out in front to form skids. A great many cross-wires and bracing wires are used, considerably complicating the structure.

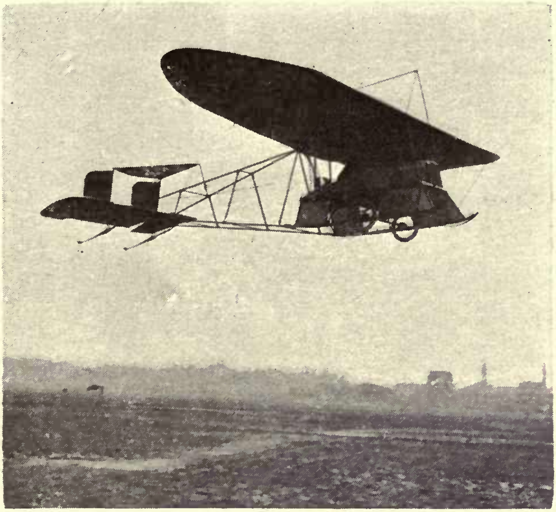
The Supporting Plane.—The main surface is perfectly straight in front. The rear edges are turned up slightly, as on the Etrich IV. It is claimed that this adds greatly to the stability. The plane is braced from the central frame, and its trailing edge is



PLAN AND ELEVATIONS OF THE PISCHOF MONOPLANE

warpable. The spread is 36 feet, the chord 9 feet, and the area 290 square feet.

The Elevation Rudder.—A Blériot XI. type elevation rudder is carried at the rear. The central portion is rigid, and the two outer portions movable. They are manipulated by the forward and back movement of a large lever in front of the aviator, forward for descent, etc.



THE PISCHOF MONOPLANE IN FLIGHT

The Direction Rudder.—Two identical surfaces at the rear above the elevator are the direction rudders. They are moved by a foot lever and wires.

Transverse Control.—The transverse control is obtained by warping the rear of the planes. This is done by the side-to-side motion of the large control lever.

Tail.—In addition to the fixed surface of the elevation rudder, there is also a triangular surface at the rear. Both exert considerable lift. Over and under the triangular surfaces are small vertical keels. At the front two sections of the chassis frame are

inclosed, to form vertical keels, which in turning help to avoid the effect of the low center of gravity.

Propulsion.—The propelling system of the Pischof is one of its most radical features. The motor is placed in front under the planes with a radiator in front of it and two seats in back of it, exactly as on an automobile. The motor of 60 to 70 horse-power drives by a shaft, clutch, and chains, the single variable pitch Normale 8½-foot diameter propeller, placed at the center and flush with the rear of the plane. Here for the first time is a practical and successful means of providing a monoplane with a propeller at the rear instead of at the front. Gnome, E. N. V., and Daimler motors have been used.

Seats.—The position of the aviator's seat and that of his passenger is very practical, and enables a clear view in every direction, as well as being away from the propeller slip stream, etc.

The Mounting.—The mounting is on two wheels at the front fitted with springs and two small wheels at the rear. The long skids at the front, really forming part of the frame, are fitted with small supplementary skids.

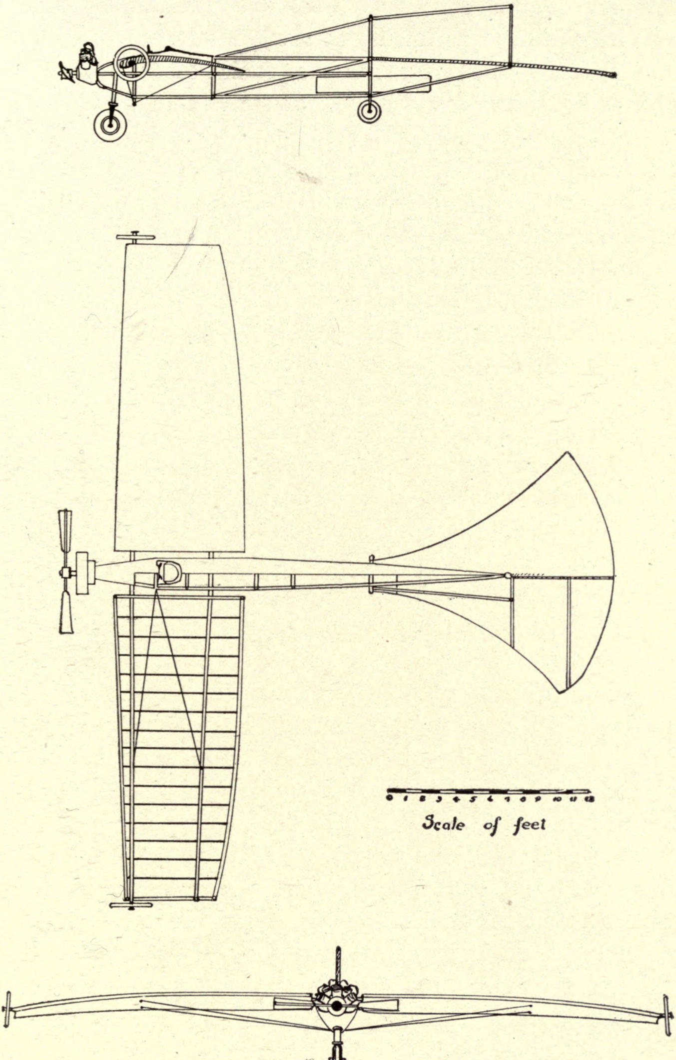
Speed, Weight, Loading and Aspect Ratio.—

The speed is high for so large a machine, 53 miles per hour often being attained. The total weight in flight is from 910 to 1,060 pounds; 17½ pounds are lifted per horse-power, and 3.65 per square foot of surface. The aspect ratio is 4 to 1.

***References.*—Flight, July 16th, 1910, p. 551; November 19th, 1910, p. 948; Aircraft, November, 1910, p. 328; L'Aero, November 17th, 1910; Rv. de l'Aviation, December, 1907; August 15th, 1908; November 15th, 1908; L'Aerophile, November, 1907, p. 328; Vorreiter, A. "Jahrbuch, 1911."**

13. THE R. E. P. MONOPLANE (1909)

The old R. E. P. monoplane was considered by many to be one of the most perfect types of aeroplanes. Great finish was exhibited in its construction and form, but due probably to motor troubles it never was flown for any great length of time. M. Pelterie, the designer, is one of the foremost aviation scientists abroad,



THE R. E. P. 1909 MONOPLANE

Side elevation plan and front elevation, showing the negative dihedral angle and wheels at ends of plane.

and previous to his experience with this machine he conducted a series of gliding experiments of great interest.

The Frame.—The central frame, somewhat similar in shape to a bird's body, was made largely of steel tubing, and was quite short. All exposed parts were covered with Continental cloth.

The Supporting Plane.—The main surface was particularly strong and solid, and was made of steel tubing carrying wooden ribs covered with Continental cloth. The curvature was very similar to that of a bird's wing, and transversely the surface curved downward dihedrally from the center. There was very little bracing necessary. The spread was 35 feet, the depth 6.1 feet, and the area 214 square feet.

The Direction Rudder.—The rudder for steering from side to side consisted of a vertical rectangular surface of 8 square feet area, placed below the central frame at the rear. It was operated by the side-to-side motion of the lever at the aviator's right hand. To turn to any side the lever was inclined to that side.

The *Elevation Control.*—There was no elevation rudder in the 1909 Pelterie monoplane, the elevation of the machine being regulated by changing the incidence of the main plane itself. To ascend, for example, the aviator pulled the lever in his left hand toward him. This increased the incident angle of the plane and the consequent increase of lift caused the machine to rise.

Transverse Control.—Each half of the main plane was warpable about its base, and transverse equilibrium was obtained by an inverse warping of the plane. The side-to-side motion of the left-hand lever controlled the warping. If the machine was tipped down on the right end the lever was moved to the left and the machine brought back to an even keel. In turning to either side both the left-hand lever controlling the warping and the right-hand lever controlling the direction rudder were simultaneously moved to that side. This was a very effective controlling system.

Keels.—Vertical and horizontal keels, consisting of gradually tapering surfaces, were fixed to the frame and aided in preserving stability. The rear horizontal keel, shaped like a bird's tail, had an area of 20 square feet.

Propulsion.—A 7-cylinder 35 horse-power R. E. P. motor, placed at the front, drove direct a four-bladed aluminum and steel propeller at 900 r.p.m. The diameter of the propeller was 6.6 feet, and the pitch 5 feet.

The Seat was placed in the frame, and protected on all sides. The aviator's shoulders were flush with the surface.

The Mounting was mainly on a large single wheel with an oleo-pneumatic spring in the center at the front and a smaller one in the same center line at the rear. When first starting the aeroplane was inclined, resting on one end of the plane, on each end of which a wheel was placed.

Weight, Speed, Loading and Aspect Ratio.—

The total weight was from 900 to 970 pounds. The speed was 39 miles per hour; 27 pounds were lifted per horse-power, and 4.4 pounds carried per square foot of surface. The aspect ratio was 5.75 to 1.

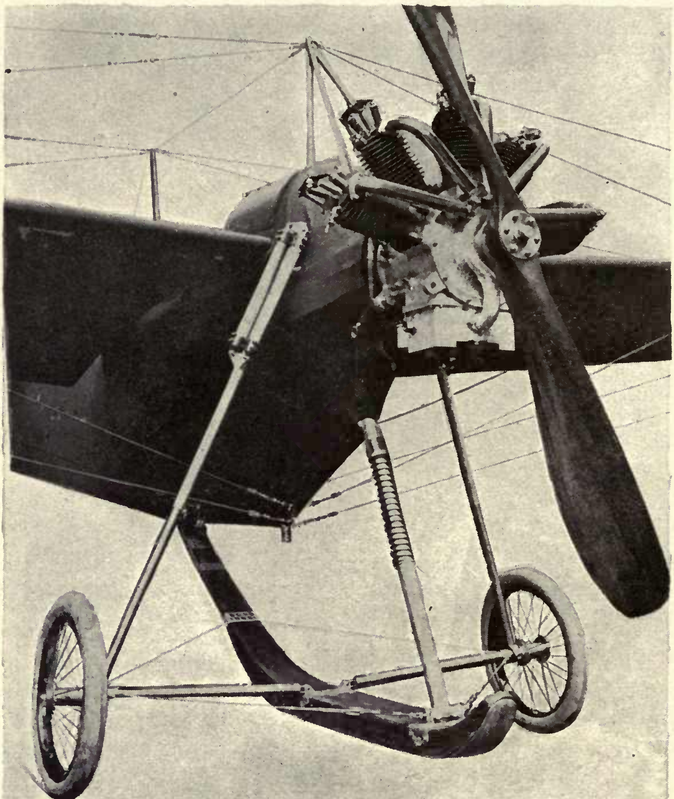
References.—Soc. des Ing. Civ., v. 2 (1908), p. 13; Boll. Soc. Aer. Ital., v. 6, pp. 67, 288; Aerophile, v. 15, p. 331; v. 16, p. 226; v. 17, p. 33; Flight, v. 1, pp. 19, 360; Aeronautical Jour., v. 13, p. 64; Zeit. für Luftschiff, v. 12, p. 458; Aeronautics, v. 4, p. 21; La France Aerienne, v. 14, Nos. 7, 9; Zeit. Ver. Deut. Ing., v. 53, p. 1760; Genie Civil, v. 55, p. 346.

14. THE R. E. P. 1911 (ONE-SEAT)

The newest product of M. Esnault-Pelterie differs radically from the older type in the method of elevation control and in the construction of the tail as well as in propeller, motor, etc. This type is built in two sizes (one or two seater) and preserves in great measure the graceful lines of its predecessors. In view of the recent excellent flights of Laurens and Bournique, with and without passenger, and because of its high speed, reliability and stability the scarlet bird-like R. E. P. has at last taken its rank among the very best flying machines of the day. Bournique on the small R. E. P. flies at 60 miles an hour, and only recently M. and Mme. Laurens established a passenger speed record. Bournique on December 31st, 1910, in competition for the Michelin cup, flew this type 331 miles.

The Frame.—The splendid non-soldered steel-tube construction of the frame gives great strength and durability. In the minutest details the R. E. P. exhibits excellent workmanship. All joints are welded.

The Supporting Plane.—The plane is similar in shape and structure to the old R. E. P. It is fixed to the central frame by

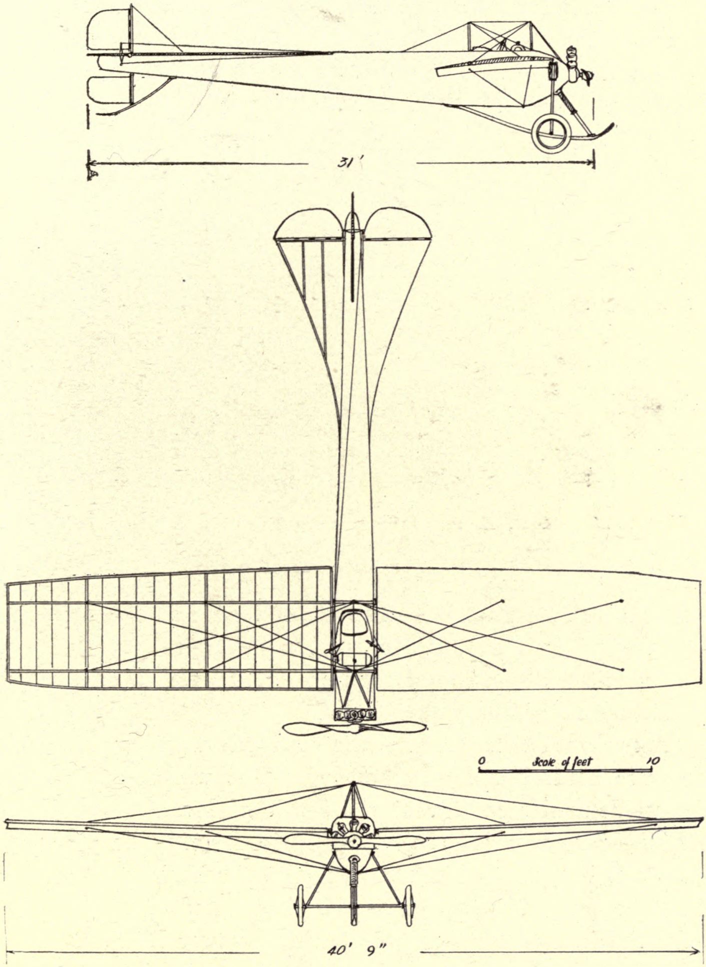


Courtesy of "Flight."

THE FRONT OF THE R. E. P. (1911)

Showing the landing chassis, motor, propeller and part of body. The wheel axles are pivoted to the central skid. The skid itself is fitted with a strong spring.

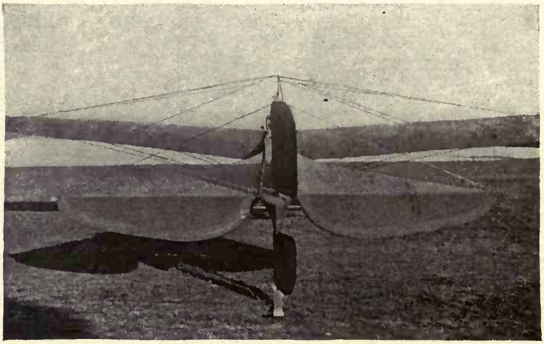
four cables, and its incidence cannot be changed as formerly. It is, however, warpable. The two halves are set at an upward dihedral angle, and not turned down as on the old type. The material used is a red vulcanized cotton fabric. The cables used



SIDE ELEVATION, PLAN AND FRONT ELEVATION OF THE 1911 ONE-SEAT R. E. P.

to support the frame are more numerous, and the plane is braced both above and below. The frame consists of two main steel laterals with ribs having an I-section. The spread is 42 feet, the mean chord 6½ feet, and the area 270 square feet.

The Elevation Rudder.—The elevation rudder consists of two flaps on the end of the horizontal tail. The alteration of the incidence of the main planes to control elevation is entirely discarded in this type. The elevators are controlled by the to-and-fro motion of the left-hand lever.



THE 1911 R. E. P. AS SEEN FROM BEHIND, SHOWING THE REAR TAIL AND RUDDERS, AND AT THE FRONT, THE MAIN PLANE

The Direction Rudder.—Two small planes at the rear, moved jointly, serve as the direction rudder. They are operated either by the side-to-side motion of the right-hand lever, as on the former type, or by an ordinary foot pedal.

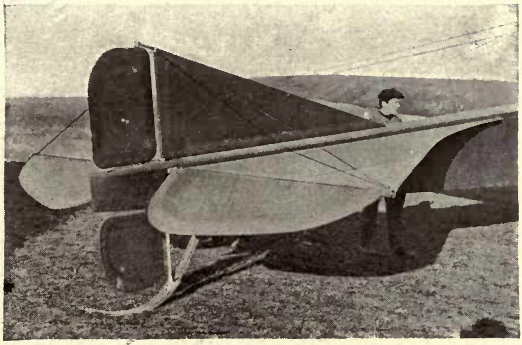
Transverse Control.—The widely used warping method of transverse control is here employed. The warping is controlled by the side-to-side motion of the left-hand lever.

Tail.—The rear is greatly altered in form. The vertical *empennage* is very much smaller, as is also the horizontal non-lifting tail. The entire tail can readily be dismounted.

Propulsion.—A five-cylinder 55 horse-power R. E. P. motor is installed at the front, and the recent success of this type is largely

due to the great improvements in this motor. The two-bladed 8¼-foot wooden Regy propeller is driven direct at a speed varying between 500 and 1,250 r.p.m. The four-bladed propeller formerly used is discarded.

The Mounting.—The mounting is altogether different from the old type, and is very simple. The single central wheel is abandoned, and in its stead is a large skid fitted by a springy telescoping steel tube to the main *fuselage.* A steel-tube frame and axle



THE RUDDERS AND TAIL OF THE 1911 R. E. P.

also support two rubber-tired wheels, one on either side of this skid, fitted with rubber rope springs. A small skid is fixed at the rear. No wheels are placed on the ends of the plane.

The *Seat* is placed as formerly, and is well protected.

Speed, Weight, Loading and Aspect Ratio.—

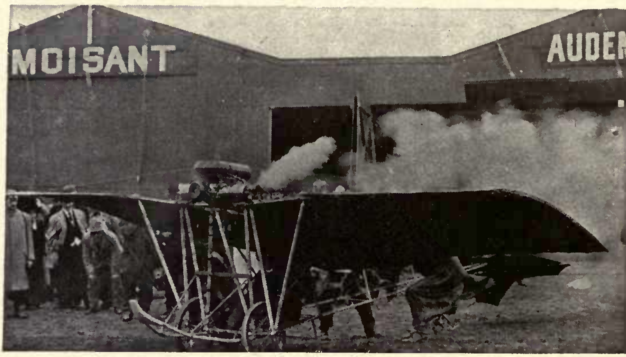
The speed is almost 60 miles an hour. The total weight is from 1,180 to 1,240 pounds; 22.5 pounds are carried per horsepower, and 4.6 per square foot of surface. The aspect ratio is 6.5 to 1.

References.—"Neve Flugzeuge in Paris," Zeit. für Flug. u Motor, November 26th, 1910; Flight, 1910, October 22nd, p. 862; October, 29th, p. 880; L'Aero, 1910, October 28th; December 1st; Aero, 1910, October 26th; November 2nd, p. 350; November 16th; Flugsport, October 19th, 1910.

15. THE SANTOS-DUMONT MONOPLANE

The first sustained flight of a motor aeroplane in Europe was made by M. Santos-Dumont on November 12th, 1906, in a biplane of his design. In 1907 he began work on a monoplane, and after much alteration, has finally evolved the highly successful and interesting little monoplane, the "Demoiselle." This is the smallest aeroplane in use to-day. Many machines of this type are being flown abroad, and their simplicity renders them quite popular.

The Frame.—The frame, which narrows toward the rear, is made of bamboo and steel joints, with several members of metal tubing.



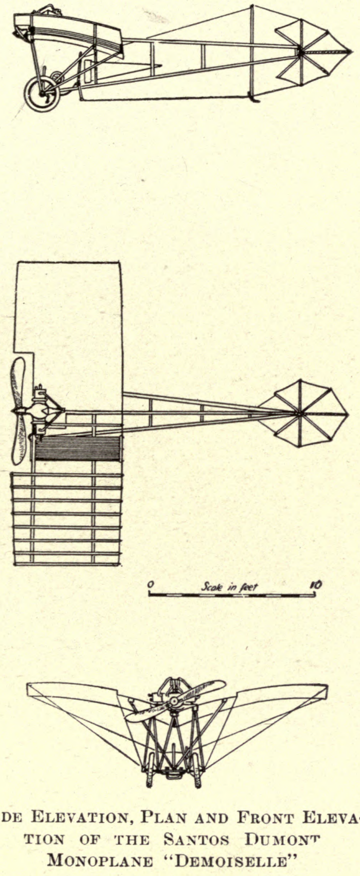
AUDEMARS ON HIS "DEMOISELLE" ABOUT TO START ON A SPEEDY LAP AT BELMONT PARK

The propeller, at the front, is rotating so fast that only the hub is visible. Note how the smoke is blown back by the propeller draught.

The Supporting Plane.—The supporting plane has both sides slightly turned up from the center, and consists of a double layer of silk stretched very tightly over bamboo ribs. The plane is braced by wires to the central frame. The curvature is approximately the arc of a circle. The spread is 18 feet, the depth 6.56 feet and the area 113 square feet.

The Direction Rudder and the Elevation Rudder.—The two rudders are combined at the rear into two fan-shaped surfaces, one

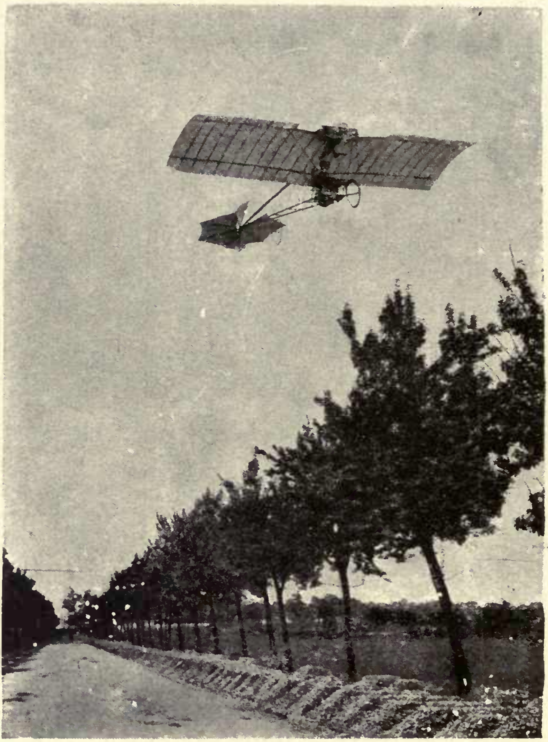
vertical and the other horizontal. They are pivoted on a single universal joint. The elevation rudder is 21 square feet in area, while the direction rudder is somewhat less. A lever at the aviator's right hand controls the movement of the elevation rudder,



SIDE ELEVATION, PLAN AND FRONT ELEVATION OF THE SANTOS DUMONT MONOPLANE "DEMOISELLE"

while a small steering wheel at the aviator's left hand controls the direction rudder. To rise the tail is moved up, while to turn to the right it is moved to the right.

Transverse Control.—Transverse control is effected in the Santos-Dumont by the warping of the main planes. This action is governed by a lever at the back of the aviator, and which fits into a socket sewed on his coat. If the aeroplane should suddenly



SANTOS DUMONT TRAVELLING ACROSS COUNTRY

tip up on the left, then the aviator, by moving quickly to the left, pulls down and increases the angle of incidence of the right side of the plane. The ribs of the plane are flexible in this machine.

Keels.—There are no keels in the Santos-Dumont monoplane.

Propulsion.—A 30 horse-power water-cooled Darracq 2-cylinder motor placed on the top of the plane at the front drives direct

a 2-bladed Chauviere wooden propeller 6.9 feet diameter and 6 feet pitch at 1,400 revolutions per minute. Clement-Bayard and Panhard motors are also used on this type of monoplane.

The Seat is a strip of canvas placed across the frame below the main plane.

The Mounting consists of two wheels at the front and a skid at the rear. No springs are provided on the wheels.

Weight, Speed, Loading and Aspect Ratio.—

The total weight is from 330 to 370 pounds; the speed is 55 miles per hour; 12 pounds are lifted per horse-power and 3.1 pounds per square foot of surface. The aspect ratio is 3 to 1.

References.—Flight, v. 1, p. 603; Sci. American Sup., v. 68, p. 317; Sci. American, v. 97, p. 445; v. 99, p. 433; Aerophile, v. 15, p. 313; v. 16, p. 468; v. 17, pp. 435, 488; L'Aviation Ill., No. 34, p. 3; La France Aerienne, v. 14, p. 608; Omnia, No. 200, p. 281; Encyl. d'Av., v. 1, p. 126; Vorreiter, A., "Motor Flugapparate"; Zeit. Ver. Deut. Ing., v. 53, p. 1762; Genie Civil, v. 55, p. 466.

16. THE SOMMER MONOPLANE

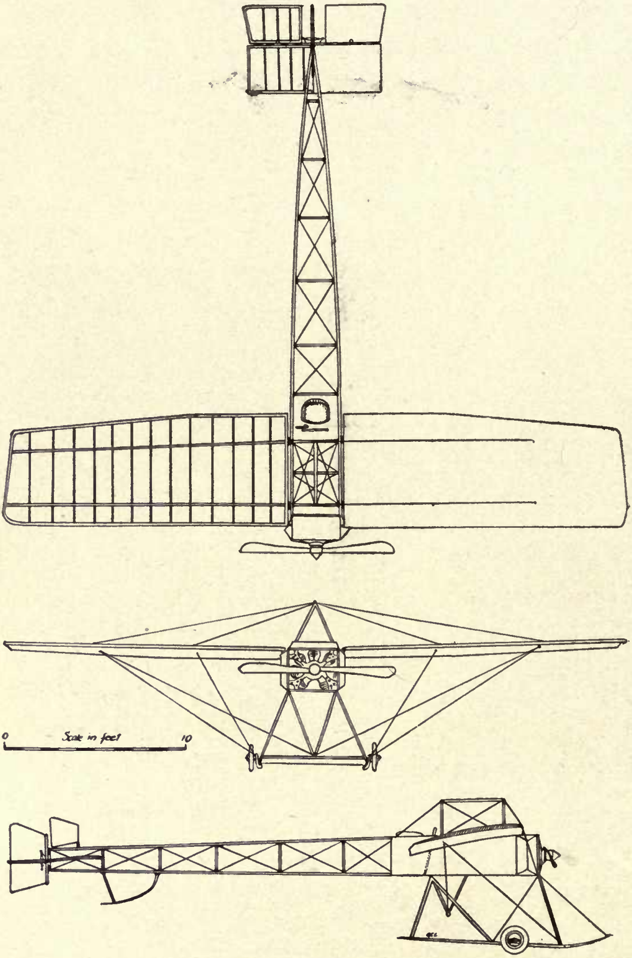
M. Roger Sommer has recently brought out a monoplane which follows regulation lines, but is exceptionally strong. In this machine M. Sommer at Douzy has already made many creditable flights. The general aspect reminds one of a Blériot *fuselage* mounted on a biplane chassis.

The Frame.—The central frame *fuselage* is of the ordinary wood and wire construction covered for some distance under the wings. There is a Blériot XI. type frame above the plane to which it is braced.

The Supporting Plane.—The plane is divided into two halves set at a dihedral angle, braced by wires to the central frame, and strongly resembling the Blériot. The spread is 34½ feet, the chord 5½ feet, and the area 183 square feet. The main transverse member of the frame of the planes is a huge I-beam of wood.

The Elevation Rudder.—Two flaps fitted on the trailing end of a weight-carrying horizontal *empennage,* form the elevation rudder. They are controlled by a large lever as on the Sommer biplane. All control wires are duplicate

The Direction Rudder.—A single surface placed between the two flaps of the elevator serves as the direction rudder, and is moved by means of a foot pedal in the usual manner.



THE SOMMER MONOPLANE

Note the splendid landing chassis.

Transverse Control.—The planes are warped by means of the side-to-side motion of the large control lever, a movement to the left causing the right side to ascend.

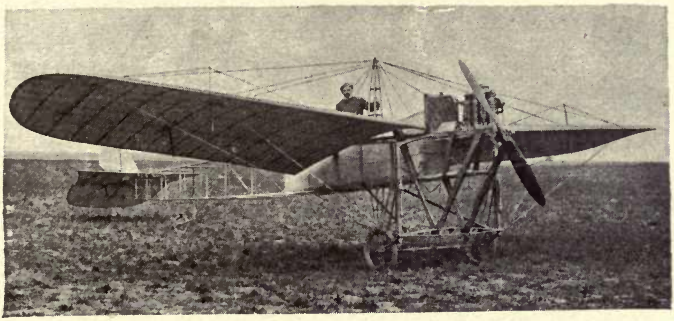
Propulsion.—A 50 horse-power seven-cylinder Gnome motor is placed at the front and almost completely boxed in. It drives direct a two-bladed "Rapid" propeller, 8.3 feet in diameter, at 1,200 r.p.m.

Mounting.—The mounting is on two main skids supported by framework to the *fuselage,* and across which is fitted an axle with rubber springs and carrying a rubber-tired wheel at each end. At the rear is a cane skid.

Speed, Weight, Loading and Aspect Ratio.—

The speed is about 54 miles an hour. The total weight is 690 pounds, making the pounds carried per horse-power 14, and the pounds per unit surface 3.8. The aspect ratio is 6.2 to 1.

References.—Aero, 1910, October 26th, November 2nd; Zeit. für Flug. und Motor, 1910, November 12th, p. 278; November 26th.

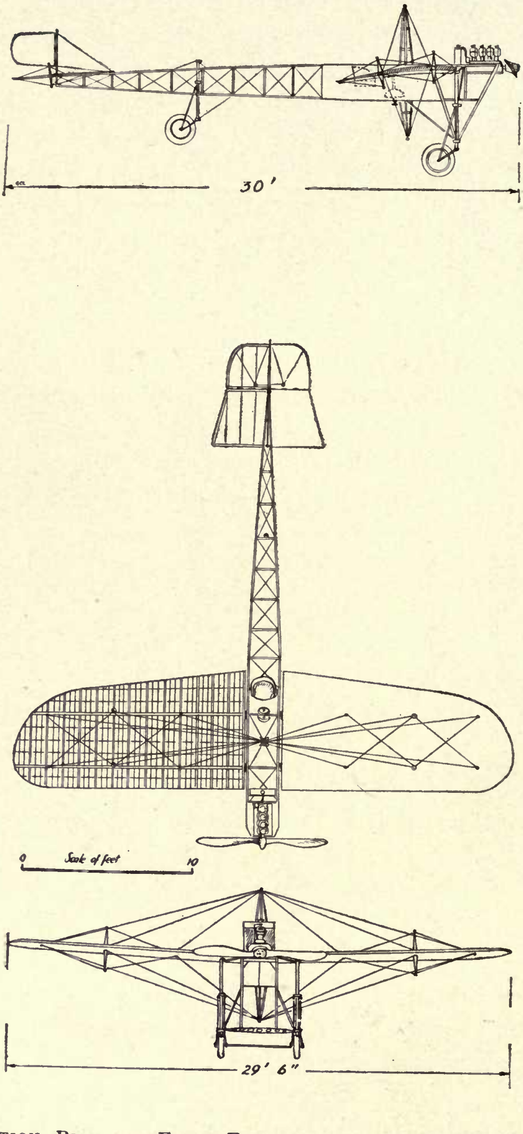


Courtesy of "Flight"

THE TELLIER MONOPLANE

17. THE TELLIER MONOPLANE

The Tellier monoplane flown by Dubonnet was so manageable that he obtained his pilot's license on his fourth outing, and occupied the commissioners only half an hour. Shortly thereafter



SIDE ELEVATION, PLAN AND FRONT ELEVATION OF THE TELLIER MONOPLANE

he made a wonderful flight over Paris, and since then Dubonnet as well as others have shown the Tellier to be a peculiarly strong and reliable machine. It is very much like the other French monoplanes in general aspect. but differs considerably in the shape of the tail, frame-work, etc.

The Frame.—The frame is a very light and strong wood and cross-wire construction, and resembles the Blériot frame. At the center between the two halves of the plane is a large frame mast, and this, with the struts out on the plane, makes the bracing very similar to the Antoinette.

The Supporting Plane.—The plane is divided into two halves set at a small dihedral angle, and more solidly built up with wooden ribs and spars than is customary. The planes are therefore exceptionally strong. They are mediumly curved, and about 3 inches thick at the center. The planes are very strongly braced, and are covered on both sides. The spread is 29½ feet, the chord (maximum), 7½ feet, and the surface area, 220 square feet. A two-passenger type of this machine is built, in which the spread is 38¾ feet, the chord 8 feet, and the area 280 square feet.

The Elevation Rudder.—At the rear is a trapezoidal-shaped horizontal keel, and hinged to the rear of this is the single-surface elevation rudder. Several different types of control have been used, the most common being a Blériot *cloche,* on which the wheel moves. To-and-fro motion is for elevation or depression.

The Direction Rudder.—The single direction rudder at the rear is placed above the elevation rudder. It is operated by a steering wheel mounted on the Blériot type *cloche,* and turned as usual, clockwise for a turn to right.

Transverse Control.—The planes are warped by the side-to-side motion of the *cloche,* as usually done.

Tail.—Beside the horizontal tail surface already mentioned, there is a small triangular vertical keel just in front of the direction rudder.

Propulsion.—On the small type a four-cylinder Panhard 45 horse-power motor is used, and drives direct a two-bladed wooden propeller 8 feet in diameter. On some of the larger types a six-

cylinder 60 horse-power Panhard is used. R. E. P. motors are also fitted.

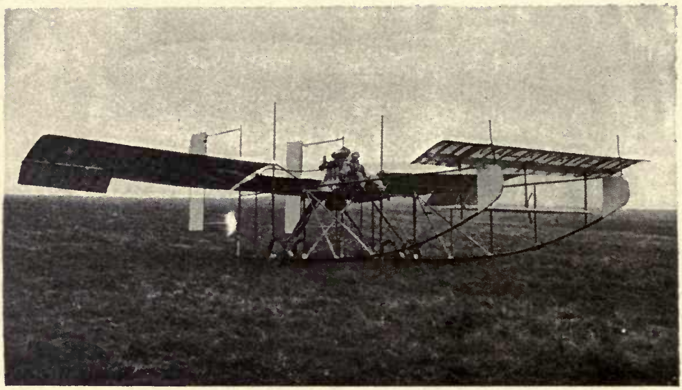
Mounting.—This machine is mounted on three wheels, two at the front and one smaller one at the rear. The two at the front are mounted on springs and on an elaborate chassis.

The *Seat* is comfortably placed near the rear of the main surface.

Speed, Weight, Loading and Aspect Ratio.—

The speed is 53 miles an hour. The total weight is 850 to 900 pounds; 19 pounds are lifted per horse-power, and 4 per square foot of surface. The aspect ratio is 4.2 to 1.

References.—Aero, 1910, October 26th; November 2nd, p. 350; November 9th, p. 364; Flight, 1910, August 6th, p. 621; September 17th p. 754; p. 759; October 29th, p. 882; December 3rd, p. 991; L'Aerophile, 1910, March 22nd, p. 151; July 15th, p. 317.



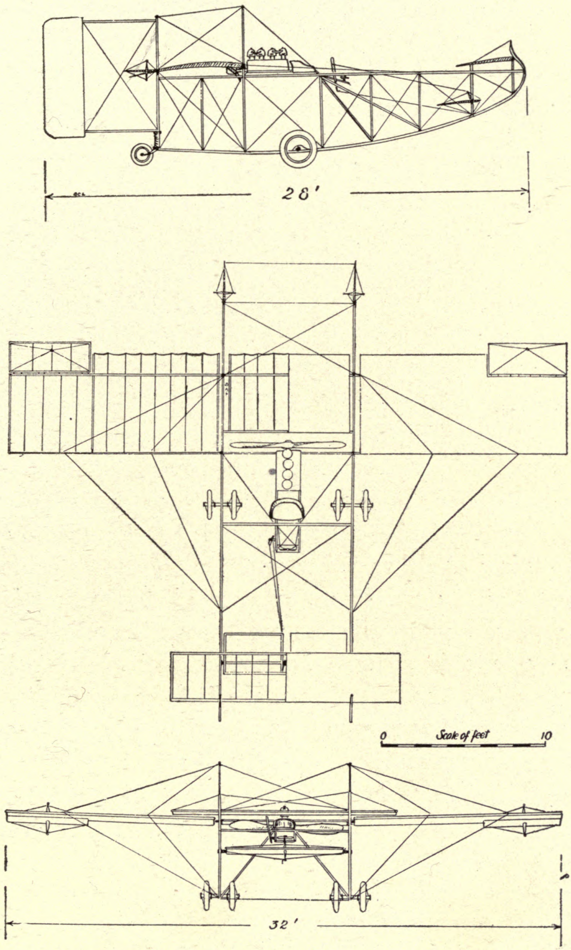
THE VALKYRIE MONOPLANE

18. THE VALKYRIE MONOPLANE

This interesting aeroplane, designed and built by the Aeronautical Syndicate, Ltd., in England, is so distinct a departure from usual monoplane practice, that it has excited a great deal of comment. Many excellent flights have already been made on this

"All-British" machine, and it is speedily taking rank among the prominent types.

The Frame.—A very fine quality of Honduras mahogany is used almost exclusively in the framework. The main members of the frame are two very long skids, upon which the rest of the



SIDE ELEVATION, PLAN AND FRONT ELEVATION OF THE VALKYRIE MONOPLANE

frame is built up. These skids are wide apart, and take the place of a central chassis.

The joints of the frame are made of aluminum and are very neat.

The Supporting Plane.—The main plane is made in three sections, the one between the frames and back of the propeller having a similar chord and less incidence than the other sections because of its position in the slip stream of the propeller. The two outer sections of the plane are turned up slightly, giving a dihedral angle effect. The surfaces are made of one layer of an Egyptian cotton fabric stretched tightly over numerous wooden ribs. The plane is braced by cables to the struts and frame of the central section. The spread is 32 feet, the chord 6½ feet, and the surface area 190 square feet.

The Elevation Rudder.—Out at the front, under the horizontal front fixed keel plane, is the single-surface elevation rudder. This is operated by wires leading to a lever which is moved to and fro, as on the H. Farman biplane. The elevator is 8 feet wide, 2½ feet deep, and 20 square feet in area.

The Direction Rudder.—Two identical surfaces at the rear serve as direction rudders. They are controlled by a foot pedal or by the side-to-side motion of the lever, as desired.

Transverse Control.—Ailerons fixed to the trailing edge of the main surface at either end control the transverse balance. They can be operated by pedals or by the side-to-side motion of the lever, as desired. These ailerons are 5 feet wide and 2 feet deep.

Keels.—There is a large horizontal keel placed well out in front, and called the "leading plane," 14 feet wide and 3 feet deep. It exerts a considerable lift, and is set at a greater incident angle than the main surface, thus employing the principle of the dihedral angle for longitudinal balance. The incident angle of this plane can be altered at will. There is no rear tail.

Propulsion.—A 30 horse-power Green engine, placed at the center in front of the main plane, drives direct a 7¼-foot propeller at 900 r.p.m. The position of the propeller is a curious one, working as it does in a slot in the framework.

Mounting.—The mounting of this machine on the strong and serviceable skids is one of its distinguishing features, and one which has been highly praised. There is little doubt that in rough landings a framework of this kind is about as safe and strong as could be desired. It resembles the old Wright frame in many respects. On each skid at the front, below the seat, is fitted a pair of wheels attached by springs, and at the rear are two smaller wheels.

The *Seat* is very conveniently placed out in front of the motor as regards comfort, but in case of accident this disposition is dangerous.

The center of gravity is very far forward, and necessitates a considerable lift on the part of the "leading plane."

Speed, Weight, Loading and Aspect Ratio.—

The speed is about 46 miles an hour. The total weight in flight is 670 pounds; 22½ pounds are lifted per horse-power, and 3.5 per square foot of surface. The aspect ratio is 5 to 1.

A racing type "B" and a passenger type "C" are also built.

References.—Flight, 1910, October 1, p. 792; November 5th.